FINAL REPORT

Assisted Migration as a Management Tool in Coastal Ecosystems Threatened by Climate Change

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14. ABSTRACT

Coastal ecosystems are among the first directly impacted by hurricane disturbance and chronic sea-level rise. Studies that explore responses of coastal biota to climate change are needed to develop adaptation strategies, but mechanisms underlying upslope establishment are poorly understood. The hypothesis tested in this study was that inland migration of downslope species is impeded by upslope vegetation. These barriers can be disassembled by hurricane storm surge, providing opportunities for seaward species to establish inland. Results indicate that inland communities are more vulnerable to storm surge, particularly when surges are more sustained and lead to sediment deposition. "Ecologically naïve" vegetation will be impacted most by these events, leading to compositional changes. Where dispersal is limited, upslope and inland establishment of species can be expedited through assisted migration. Vegetation cover is helpful for new transplants, but its removal appears to benefit later survival of transplants when competition may pose a bigger challenge. Species that are transplanted must be tolerant of disturbances, such as fire, that are typical in their new, upslope habitats. Deliberate, assisted migration can be prescriptive and futuristic if these management efforts are matched with climate change projections; it may be necessary where dispersal is limited by natural and anthropogenic barriers.

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List of Acronyms

AFB – Air Force base
NMDS – non-metric multidimensional scaling
PC-ORD – software package for conducting multivariate statistical analysis
PERMANOVA – permutational analysis of variance
PRIMER – software package for conducting multivariate statistical analyses
PVC – pipe made from polymerized vinyl chloride
SAS – software package for statistical analyses

Keywords

Assisted migration, Climate change, Coastal ecosystems, Hurricane, Storm surge

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Abstract

Objective —Low-lying coastlines are among the first ecosystems directly impacted by hurricane disturbance and chronic sea-level rise. Studies that explore responses of coastal biota to climate change are needed to develop adaptation strategies. Coastal species may cope with environmental changes over the short term, but eventually they will be eliminated unless inland migration can occur. The mechanisms underlying successful upslope establishment are poorly understood. The main hypothesis tested in this study was that inland migration of downslope species is impeded by upslope vegetation composed of species largely intolerant of salinity and deposition pulses. These biological barriers can be disassembled by hurricane-generated storm surge, followed by a reshuffling of community assemblages, and opening of opportunities for species from seaward positions to establish further inland.

Technical Approach—In early Summer 2009 five transects were established at points along East Bay River, a tidal river ecosystem on Eglin Air Force Base in northwestern Florida that encompasses saline to fresh water conditions. Each transect was surveyed for elevation and extended perpendicular to the river into upland habitat to include 1-meter, 2-meter, and 3-meter changes in relative elevation from river's edge. In August 2009 nine vegetation plots were located haphazardly in each of the three elevation classes alongside each transect (n = 135). Three plots were designated controls, three were assigned to a single surge treatment, and three plots were assigned to a double surge treatment with a two-year interval separating the surge applications (Experiment 1). In 2010 a second set of plots (n = 135), similarly organized with random assignments to the three surge treatments, was established along each of the transects. Plots established and initially surged in 2010 also received propagule additions of dominant native species from across the estuarine gradient. In addition, the volume of saline water applied for the second surge application in 2012 was doubled (Experiment 2). All vascular plant species were identified and their cover estimated in each plot prior to experimental storm surge treatments and annually thereafter through the 2013 growing season. In 2010, a third set of plots was established (n = 75) to test the effects of storm surge that included sediment deposition (Experiment 3). Composition was surveyed on an annual basis in control and treatment plots following the surge treatments (2010 to 2013). In 2011, a reciprocal transplant experiment (Experiment 4) was initiated to investigate the feasibility of upslope, assisted migration of dominant species representing different parts of the gradient, with and without removal of standing vegetation (n = 135 plots).

Results—Compositional trajectories differed significantly among years and elevation zones but communities were largely resilient to experimental storm surge disturbances and showed no significant differences between surge treatment levels, except along one of the inland transects (Experiment 1). In contrast, plant composition exhibited significant change with surge treatment effects, which were part of higher order interactions that included time and elevation in Experiment 2. Propagule additions had no discernible effect on post-disturbance recovery. In general, community disassembly was less pronounced near the bay where halophytes adapted to regular tidal inundation dominate; disassembly was greatest in upslope and upstream communities. Trajectories of the high and intermediate elevation communities, located along the two most inland transects, were also influenced by two prescribed fires in Experiments 1-3. Disassembly was greatest and vegetation recovery slowest in plots that received a second,

double-volume storm surge (Experiment 2) and where sediment was added to the surge waters (Experiment 3). Compositional shifts were largely driven by *in situ* mortality and reduced abundance of species intolerant of the surges, rather than upslope migration of species. Several species emerged as key indicators of elevation-specific responders (e.g., winners and losers) to storm surge treatments. Two of the transplanted species, the brackish marsh dominant *Juncus roemerianus* and fresh marsh dominant *Cladium mariscus,* exhibited multi-year survival in plots spanning the estuarine and elevation gradients (Experiment 4), including habitats that received prescribed burns.

Benefits—Collectively, Experiments 1-3 indicate that inland communities are more vulnerable to the effects of storm surge, particularly when the surges are more sustained and lead to sediment deposition. Taken together with climate change models that project increasingly common intense tropical storms, these results suggest that “ecologically naïve” vegetation will be impacted most by these events, leading to substantial compositional changes. The initial winners will be species that are resilient to these events, and the losers will be ones that are sensitive. Where mortality is high and recovery is limited or slow, regeneration windows may be longer lived such that some downslope species are capable establishing in upslope habitat. Distance from source population and dispersal distance will be factors that influence the rate of inland migration.

Upslope and inland establishment of some species can be expedited through assisted migration. Vegetation cover may be beneficial for newly transplanted individuals, but removal of standing vegetation appears to have positive effects on later survival of transplants when competition may pose a bigger challenge. Species that are transplanted must be tolerant of disturbances, such as fire, that are typical in their new, upslope habitats.

This research can inform management regarding ecological scenarios consistent with climate change forecasts and provide a potential tool for intervention. Chronic and acute disturbances (i.e., sea level rise, storm surge, fire) are drivers that have complex effects on movement of coastal species. As disturbance regimes are altered by climate change, they are likely to cause shifts in species’ distributions in unpredictable ways. Movement of species is also influenced by barriers in the landscape; methods to overcome these obstacles will be increasingly important as the climate envelopes of species change spatially. Deliberate, assisted migration can be a prescriptive and effective approach if management efforts are matched with climate change. This type of intervention may be especially necessary when dispersal is limited by natural and anthropogenic barriers.

Objective

Low-lying coastlines are among the first ecosystems directly impacted by hurricane disturbance and chronic sea-level rise. Coastal species may cope with environmental changes over the short term, but eventually they will be eliminated unless inland migration can occur. Unfortunately, the mechanisms by which species successfully migrate inland/upslope are poorly understood. This gap in our understanding limits development of effective and appropriate management strategies for adaptation to climate change. The objective of this research is to test the effects of potential migration drivers using a series of integrated field experiments, with the goal of filling some of those knowledge gaps.

The main hypothesis tested in this study was that inland migration of downslope species is impeded by upslope vegetation composed of species largely intolerant of salinity and deposition pulses. These biological barriers can be disassembled by hurricane-generated storm surge, followed by a reshuffling of community assemblages, and opening of opportunities for species from seaward positions to establish further inland. A secondary, related hypothesis is that assisted migration can be a viable tool for moving species inland and that establishment success of transplanted species will be greater where existing vegetation cover is removed/reduced. This study is designed to explore responses of coastal biota to the projected impacts of climate change and provide crucial information that will be needed to develop effective adaptation strategies.

Background

Studies that explore potential responses of coastal biota to climate change are needed to gain a better understanding of how species cope or fail to cope with these changes. Unfortunately, coping mechanisms are poorly understood but a working understanding is needed to inform management and to provide the foundation for adaptation strategies. The main objective of this research was to test the effects of shifting tropical storm regimes, in the context of global warming and sea level rise, on coastal plant community disassembly and reassembly. Previous work indicates that squeezing of coastal vegetation may occur if landward vegetation constitutes a barrier to upslope migration (Shirley and Battaglia 2006, 2008). However, natural disturbances may remove these barriers (Tate and Battaglia 2013) and promote reestablishment *in situ*, landward expansion of distributions (Pivovaroff et al. 2015), or establishment of new assemblages (Platt et al. 2015). Following canopy disturbance by Hurricanes Ivan (2004) and Katrina (2005), upslope establishment of several marsh species (*e.g.*, *Cladium mariscus* and *Solidago sempervirens*) was observed along the coastal transition at Weeks Bay National Estuarine Research Reserve in Alabama. These findings suggest that competition, particularly for light, is a strong filter that limits establishment of herbaceous marsh species at the leading, landward edge of their distributions (Crain et al. 2004). The overarching hypothesis of this study is that hurricane-generated storm surge disassembles landward communities dominated by species intolerant of high salinity pulses, which may enable species from seaward positions to establish further inland. For some species that are dispersal limited, assisted migration (or managed relocation) may be necessary for them to persist in the system (Hoegh-Guldberg et al. 2010).

Assisted migration efforts can include movement of propagules into more suitable habitat to overcome dispersal limitation, as well as removal of upslope vegetation. This research is innovative because it is the first to focus directly on mechanisms of coastal species migrations in the context of climate change-driven shifts in disturbance regimes. Global warming has been hypothesized to increase hurricane intensity in this region (Bender et al. 2010, Edenhofer et al. 2014), which could have strong effects on the ability of coastal species to maintain viable populations along estuarine-upland coastal transitions. For example, communities that are part of the coastal landscape but positioned farther inland rarely experience saline intrusions and are therefore likely to harbor species that are particularly sensitive to these changing conditions (Abbott and Battaglia 2015). Thus, disturbances that create opportunities for inland migration may be critical for landscape fluidity and maintenance of biodiversity (Manning et al. 2009).

Milestones

All of the milestones associated with the Natural Regeneration Experiment (#1), the Propagule Addition Experiment (#2), the Sediment/Surge Experiment (#3), and the Habitat Modification Experiment (#4) were met.

Milestones for experiments #1 and #2 included establishment of transects and vegetation plots, pre-treatment surveys of the plots, application of storm surge and propagule enhancement treatments, annual post-treatment surveys from initiation of each study through 2013, data entry and proofing, statistical analyses, and summaries of results.

Experiment #3 was an add-on study, initiated in Summer 2010. This work was developed to test the effects of sediment application, in conjunction with storm surge, on vegetation assemblages along the estuarine gradient. All tasks associated with this experiment were completed; vegetation plots were established, surveyed, the storm surge + sediment treatments were applied, and annual species composition surveys were conducted 2010-2013. Data entry, proofing, statistical analyses and summaries of results were completed.

The habitat modification experiment (#4) was originally scheduled to begin in Summer 2010 but was delayed until August 2011 because setup of the second surge study and the sediment experiment took longer than expected and monopolized the 2010 field season. Sampling along the most upstream transect was complicated and delayed due to a prescribed (but unexpected) fire that occurred in early summer 2010. This fourth experiment was finally set up (n=135) in August 2011. Nine $4m^2$ plots were established and marked in each gradient/elevation combination. Vegetation removal was completed, and herbicide was applied. In November 2011, plants were harvested from local populations, transplanted into the plots and individually marked. Initial survival of transplants was assessed early spring 2012. Surveys of plant survival and plant condition were conducted annually in the 2012, 2013, and 2014 growing seasons. Note that the study was extended to 2014 to ensure collection of three years of data. Data entry, proofing, statistical analyses and summaries of results were completed.

Lastly, a complementary study was conducted in Summer 2014 to quantify infiltration rates of storm surge treatments into soils across the estuarine and elevation gradients (Appendix 2).

Materials and Methods

Descriptions of Plant Communities
Early reconnaissance and qualitative assessment of plant community composition indicated substantial variation in vegetation across transects and with elevation changes relative to East River. In general, the zones closest to East River were wetland communities; the intermediate zones were transitional assemblages with some overlap in composition between the wetland and upland habitats. The higher elevation communities were either a variant of the pine savannah or scrub oak/slash pine woodland.

Vegetation spanning the transect closest to East River Bay (Transect #1) had pronounced zonation correlated with topographic change. The lowest elevation zone was strongly influenced by tides. The salt marsh, dominated by *Spartina alterniflora*, formed a narrow fringe along the water's edge; the brackish marsh was more expansive and was dominated by black needlerush (*Juncus roemerianus*). The intermediate elevation zone was dominated by a mixture of hardwoods (e.g., *Acer rubrum*), slash pine (*Pinus elliottii*) and a diverse understory layer (e.g., *Arundinaria tecta*, *Chasmanthium laxum*, and *Woodwardia areolata*). The highest elevation zone was dominated by slash pine, turkey oak (*Quercus laevis*), live oak (*Quercus virginiana*) and a sparse understory layer with occasional saw palmettos (*Serenoa repens*).

The next transect upriver (Transect #2) also had pronounced zonation aligned with changes in elevation. The zone closest to the river was frequently inundated. This community was dominated by sawgrass (*Cladium mariscus*), swamp titi (*Cyrilla racemiflora*), and a mixture of freshwater wetland species (e.g., *Rhynchospora cephalantha*). The highest elevation zone had a sparse canopy of slash pine, with occasional turkey oak in the subcanopy, some dense patches of saw palmetto, frequent *Gaylussacia* spp. in the understory, and infrequent patches of herbaceous species.

On transect #3, the lowest zone next to East River was frequently inundated and contained a mixture of freshwater obligate wetland species (e.g., *Oxypolis filiformis*, *Dulichium arundinaceum*) and shrub layer dominated by swamp titi, with occasional *Juniperus virginiana* and pond cypress (*Taxodium ascendens*) in the canopy. The intermediate elevation zone contained a rich mixture of carnivorous plant species (e.g., *Sarracenia leucophylla, S. psittacina, S. purpurea, Drosera intermedia*), numerous facultative and obligate wetland herbaceous species, and a tall shrub layer dominated by swamp titi and black titi (*Cliftonia monophylla*). The highest elevation zone contained scattered slash pine, live oak, and turkey oak with sparse clumps of upland grasses and forbs.

The plant communities along Transect #4 also exhibited zonation to some degree. The lowest zone by the East River was periodically inundated and dominated by a relatively dense canopy of slash pine and pond cypress in the overstory; the understory layer was very sparse with occasional patches of freshwater herbaceous species. The intermediate and higher elevation zones were more similar in composition, with scattered slash pine in the overstory and a dense layer of herbaceous species (e.g., *Rhexia alifanus*, *Helianthus* spp.) in the understory. The pitcher plant species (*Sarracenia* spp.) were found occasionally in the intermediate zone.

Wiregrass (*Aristida stricta*) was most abundant in the intermediate zone but somewhat reduced at the higher elevation.

Transect #5 was the most inland (upriver) location. The lower elevation zone had sparse pond cypress in the overstory, patches of swamp titi and black titi in the shrub stratum, and a dense herbaceous layer dominated by grasses (e.g., *Dichanthlium scabriusculum*) and sedges (e.g., *Rhynchospora corniculata*) adapted to periodic inundation from East River. The intermediate zone was a true ecotone between this community and the higher elevation pine savanna zone. It contained dense swamp titi, other evergreen shrubs (e.g., *Lyonia lucida*) and several shrubby *Hypericum* species. The highest elevation zone was dominated by a sparse canopy of slash pine and occasional longleaf pine (*Pinus palustris*), and infrequent patches of saw palmetto in the shrub layer. The ground layer was dominated by moderately abundant dwarf live oak (*Quercus minima*) and a highly diverse herbaceous community, including wiregrass and many forbs (e.g., *Helianthus angustifolia*, *Polygala cruciata*, *Coreopsis linifolia*).

Experiment #1: Natural Regeneration Responses to Experimental Storm Surge

Field experiments were conducted to mimic two different frequencies and intensities of storm surge (expansion to increasingly upslope communities). In Summer 2009, a transect was established at each of five stations along East Bay River, a tidal river ecosystem in northwest Florida (Figure 1). Each transect was surveyed for elevation and extended perpendicular to the river into upland habitat to include 1m, 2m, and 3m changes in relative elevation from the river's edge. Community zonation and compositional turnover along such slight elevation gradients is typical for coastal vegetation assemblages along the northern Gulf of Mexico (Battaglia et al. 2012). In this experiment, nine 2m x 1m plots were established haphazardly in each of the three elevation zones alongside each transect (n = 135; Table 1). Plant species were identified and their cover estimated prior to application of experimental storm surge treatments in late August 2009 (Figure 2). Three of the plots in each elevation class along each transect were not manipulated; the remaining six plots received the surge application. Each plot assigned to the surge treatment received ~757 L of saline water during the simulated surge event. The goal of the surge treatment was to deliver an ephemeral pulse of highly saline water, mimicking a natural storm surge, of sufficient volume to create standing water on the plot that could then infiltrate into the soil. To my knowledge, an experiment of this magnitude has not been conducted before in the field and therefore, there is no literature available to suggest appropriate volume for this treatment. Three of the plots in each transect/elevation combination that were surged in 2009 were randomly selected for a second surge that was applied in late August 2011. Plots were re-surveyed annually from 2010-2013 during the growing seasons to determine patterns of community dynamics and whether the surges generated compositional shifts consistent with landward migration of species.

Non-metric multidimensional scaling ordination, using abundance-based Bray-Curtis dissimilarities (Minchin 1987), was used to explore and summarize compositional trends in the data. Repeated measures PERMANOVA was used to test whether there were differences in plot composition between before *vs*. after treatment plot composition (pre-treatment vs. two years following the second surge treatment), elevation zones, and storm surge frequency (control, 1x surge, and 2x surge) at each position of the estuarine gradient (i.e., transect location). These analyses were conducted using PRIMER software (Clarke and Gorley 2001) with the PERMANOVA add-on (Anderson et al. 2008).

Figure 1. Map depicting location of five transects adjacent to the East River at Eglin AFB in northwestern Florida. Transects are of variable length but encompass 3m change in elevation relative to East River. Transects are enumerated from seaward (#1) to inland (#5).

Figure 2. Steps in the experimental storm surge treatment. In panel A, ~757 L of water is pumped from the East Bay River into a holding tank. The holding tank is shown in panel B; here, the salinity is measured and Instant Ocean™ marine salt is added and mixed to achieve 27 ppt. In panel C, all water from the holding tank is being pumped into one of the vegetation plots.

Each plot, including the controls that did not receive a surge treatment, was trenched at a 10 cm depth along the plot boundary. The tank in panel C is bottomless and has been pounded 10 cm into the ground prior to application of storm surge water. The tank remained in place until the water completely infiltrated the soil.

Table 1. Number of vegetation plots established in each of the four field experiments. Plots established for the first two experiments (Storm Surge and Storm Surge + Propagules) are 2m x 1m. For the Storm Surge + Sediment study, plot size was $0.81 m^2$. The plots in the Habitat Modification study were $4 m^2$.

	Storm Surge	**Storm Surge + Propagules**	**Storm Surge + Sediment**	**Habitat Modification**
Stations	5	5	5	5
Elevation Zones	3	3	5	3
Treatments	3	3	1[a]	2 [b]
Replicates	3	3	5	3
Total Plots	**135**	**135**	**75**	**135**

[a] At each station/elevation zone combination, there is one plot that is designated as a control, and it is left unmanipulated (no surge or sediment application).
[b] At each station/elevation zone combination, there are three plots that are designated as control plots; vegetation was removed in the remaining six plots at the beginning of the experiment.

Experiment #2: Community Responses to Experimental Storm Surge and Propagule Additions

This study is designed to evaluate whether propagules are limiting reassembly and ability of species to establish upslope of their present position. In Summer 2010, a duplicate set of vegetation plots (n = 135) was established in the same manner as the first set (Table 1). These plots were designated to receive surge treatments, as well as propagule additions of key taxa spanning the estuarine gradient. Species composition was recorded in each plot prior to application of treatments.

A list of species from plots surveyed in the first year of Experiment #1 was used to select taxa for the propagule additions. All species selected were sufficiently common that they were considered representative of their particular vegetation assemblage (e.g., salt marsh) and collection of seed or rhizomes would not have detrimental impacts on local populations. Because degree of salinity tolerance is known to be an important determinant of species responses to storm surge and tidal regimes, selections were made to include an array of species from multiple habitat types that spanned a wide range of tolerance levels. Ten species were selected for the propagule addition: *Spartina alterniflora* (salt marsh), *Juncus roemerianus* (brackish marsh*), Baccharis halimifolia* (common at ecotone between brackish marsh and adjacent woodland), *Morella cerifera (*common at ecotone between brackish marsh and adjacent woodland and in intermediate elevation communities across the estuarine gradient) *Cladium jamaicense* (fresh marsh) *Sarracenia leucophylla* (pine savannah and intermediate elevation communities), *Liatris spicata* (pine savannah), *Helianthus angustifolia (pine savannah), Andropogon glomeratus* (pine savannah and scrub oak), and *Aristida stricta* (pine savannah). Seed viability analysis was performed using tetrazolium on a random sample of each of these species to determine the number of seeds to be added to ensure a minimum of 50 viable propagules. In the case of *Spartina alterniflora*, viability was exceptionally low and therefore nine rhizomes collected from East Bay were added to plots instead of seeds.

Soil conductivity (surrogate for salinity) was measured on samples taken from plots a month following the surge to determine short-term effects of this treatment on soil salinity. Three of the plots in each transect/elevation combination that were surged in 2010 were randomly selected for a second surge that was applied in late August 2012. This second surge treatment was double the volume of the previous one (~1514 L). Plots were re-surveyed annually from 2011-2013 during the growing seasons to quantify patterns of community dynamics and to determine whether the surges generated compositional shifts and if so, to characterize the nature of those changes.

As with the datasets from Experiment #1, multivariate data analyses were conducted to evaluate compositional trajectories and potential effects of time, elevation, and surge treatments. In addition, Indicator Species Analysis (Dufrêne and Legendre 1997) was conducted using PC-ORD software (McCune and Mefford 1999) to identify species that exhibited statistically significant fidelity and constancy to elevation and storm surge treatment groups. This analysis was also used to pinpoint instances where species used in the propagule additions may have emerged as important indicators of compositional trends.

Experiment #3: Storm Surge + Sediment Deposition

In late Summer 2010, a set of smaller $0.81 m^2$ plots ($n = 75$) was established along the established transects encompassing the estuarine gradient. This study was designed to assess the combined effects of experimental storm surge and sediment deposition on coastal vegetation dynamics (Table 1). Previous studies did not include sediment additions. Along each transect and in each elevation zone, five plots were marked and surveyed for vascular plant species composition. In each group of five plots, one was designated a control and was left un-manipulated; the others were slated to receive an experimental surge that contained sediment.

Marine sand was collected from the shallow intertidal near-shore area on East Bay near Transect #1 (Figure 1). River silt was taken from the inundated edges of East River, near Transect #3 (Figure 1). Sand and silt were bagged separately in heavy-duty contractor bags and sediment supplies were deployed along each of the five transects. This material was not tested for the presence of plant propagules. For each plot receiving a surge + sediment application, a sand and silt mixture (2:1) was applied in conjunction with the surges to achieve sediment deposition of 5 cm consistent with a previous study of sediment deposition during Hurricane Katrina (Turner et al. 2006). A month later, plots were revisited to quantify short-term patterns of plant mortality and soil water conductivity. Plots were resurveyed during the 2011-2013 growing seasons to study compositional dynamics and potential responses to the surge treatments.

NMDS ordinations, using abundance-based Bray-Curtis dissimilarities (Minchin 1987), were used to explore and summarize compositional trends in the data. In each year of the study, average dissimilarity of the surge-treated plots, relative to their respective control plot in each of the transect/elevation combinations, was calculated and displayed graphically for comparisons across elevation zones and through time.

Figure 3. Steps used for implementation of the Storm Surge + Sediment Experiment. The river silt is added to the marine sand (upper left photo). The sediment mixture (2:1 sand to silt ratio) is then applied to each plot using storm surge water pumped through hoses (bottom left photo). Each plot had ~ 5 cm sediment deposition (right photo with pen shown for scale).

Experiment #4: Habitat Modification and Assisted Migration
This study was designed as a reciprocal transplant experiment to investigate the feasibility of assisted migration, with and without removal of standing vegetation. In August 2011, a fourth group of plots (n = 135) was established in close proximity to the original transects. To ensure that these plots were not influencing plots in the other experiments, they were offset slightly but remained in the same designated elevation zones.

Nine 4m^2 plots were established and marked in each gradient/elevation combination; three plots were assigned as controls and the remaining six for vegetation removal. In the removal plots, all vegetation, woody and herbaceous, was removed using brush-cutters, clippers, and chainsaws within the plot boundaries and in a ~1m buffer zone around plot peripheries. After vegetation removal was complete, concentrated glyphosate herbicide was applied. Plots were revisited a month later, and any resprouting vegetation was again cut and sprayed with herbicide.

In November 2011, 1350 individuals of four species that represent dominant vegetation zones were harvested from local populations at Eglin AFB. These included *Aristida stricta* (pine savannah dominant), *Cladium mariscus* (fresh marsh dominant), *Juncus roemerianus* (brackish marsh dominant), and *Spartina alterniflora* (salt marsh dominant). In all cases, aboveground material was harvested, along with belowground parts that were carefully excavated such that rhizomes and roots were intact.

Each of the plots was divided into four $1m^2$ subplots, which were then randomly assigned to one of the four transplant species. Individuals were transplanted into the plots within 24 hours of being excavated. In most cases, they were planted equidistant from each other within each subplot, but that was not always possible in the control plots where standing vegetation (woody species in particular) limited space. All individuals were marked with a flag and assigned a unique numeric code. Initial survival of transplants was assessed in early spring 2012. Surveys of plant survival and plant condition were conducted annually in the 2012, 2013, and 2014 growing seasons.

Figure 4. Harvested plants were transplanted into $4m^2$ plots in the Habitat Modification Experiment. In the plot shown, existing vegetation had been removed prior to transplant introduction.

Initial survival data were summarized but not statistically analyzed, as they were largely used as a check for transplant shock and to determine whether supplemental planting was needed. For each remaining survey conducted at the end of the 2012, 2013, and 2014 growing seasons, data were analyzed using generalized linear models in SAS v. 9.2, with transect, elevation zone, and treatment (control vs. removal) and all higher order interaction terms included in the model. Percent survival data, which constituted the response variable, were arc-sine transformed, where needed to meet assumptions of normality and homoscedasticity.

Infiltration Rates

Storm surge infiltration rates could not be quantified consistently and accurately during the storm surge treatments on the plots. Vertical and lateral infiltration rates were therefore subsequently measured across the estuarine and elevation gradients on a smaller scale using PVC tubes. For vertical infiltration, three replicate holes near established plots at each elevation zone along each transect were excavated at 5 cm, 25 cm and 50 cm using a soil corer. A PVC tube (50 cm in length x 5.08 cm in diameter) was inserted into each hole and filled to capacity with 25 PPT storm surge water. A timer was used to determine time to infiltration (seconds). To determine lateral infiltration, three replicate holes were excavated at 25 cm and 50 cm using the soil corer. A 50 cm PVC tube, with small drilled holes (to the appropriate depth – 25 or 50 cm) was inserted into the hole and filled to capacity with 25 ppt storm water. Time to infiltration was determined (seconds).

Results and Discussion

Experiment #1: Natural Regeneration Responses to Experimental Storm Surge

Community composition varied substantially across the East River tidal river system. Ordination of all 135 pre-surge vegetation plots (Experiment #1) indicated that the brackish marsh species composition (0-1m elevation) had little in common with the other vegetation. These plots had low diversity and were dominated by *Juncus roemerianus* (black needle rush), a common species in the brackish marshes of the northern Gulf of Mexico (Battaglia et al. 2012, Visser et al. 2012). The cloud of points comprised of plots from the other elevation zones was highly compressed because the pattern was driven largely by their high dissimilarity to the brackish marsh zone plots. When the latter plots were omitted from the analysis, other trends in community composition were evident. Vector fitting indicated that compositional trends were significantly correlated with topographic position relative to the river and distance from the sea (Figure 5). As expected, lower elevation plots closer to the river tended to be dominated by obligate and facultative wetland species, e.g., *Cladium mariscus*, and higher elevation plots were dominated by upland species. In general, symbols of similar darkness (i.e., same elevation zone) occupied similar areas in the ordination. With distance from the sea, species tolerant of salinity dropped out. With the exception of the *Juncus roemerianus*-dominated marsh community, omitted from this analysis, trends in the ordination suggested some degree of similarity in community composition with respect to distance from sea (i.e., seaward to inland sequence as shown by the blue → green → yellow → red color transition) in the figure.

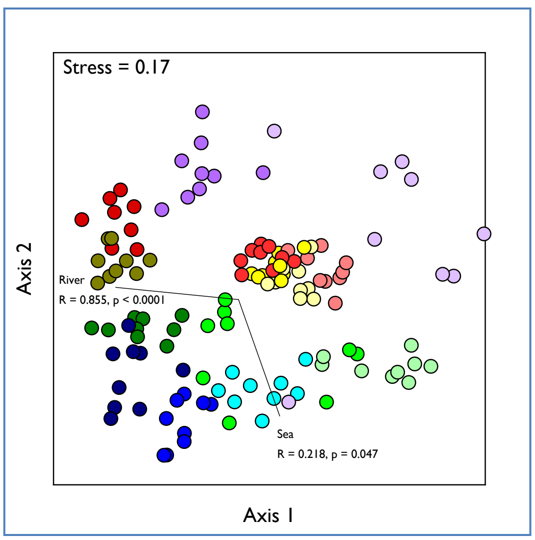


Figure 5. Two-dimensional NMDS ordination of the pre-treatment vegetation plots; nine brackish marsh plots nearest the sea were omitted. The ordination is based upon presence/absence of all vascular plant species recorded. Compositional trends are significantly correlated with distance from the sea and topographic position relative to the river at each transect, as indicated by the vectors shown. The color scheme reflects position along the coastal transition (violet: seaward transect #1; yellow: transect #2; green: transect #3; blue: transect #4; violet: most landward transect #5). Darkness of symbols within each color group codes for elevation zone relative to the river. The darkest symbols denote plots of lowest elevation that are

closest to East River (i.e., symbols in the bottom left of the ordination figure). Pale symbols represent the highest elevation plots that are farthest from the river; intermediate elevation plots have intermediate darkness.

For all five transects, trends in ordination space (Figures 6-10) suggest strong differences in composition across the different elevation zones with some additional shifts over the four-year period. In all of these cases, PERMANOVA indicated significant time x elevation interactions (Tables 2-6). Elevation groupings were highly defined, although shifts across the four-year study (pre-treatment to 2012) were not consistently directional. The statistically supported elevation groups are not surprising and reflect typical patterns of turnover in coastal species along flooding and salinity gradients. Compositional shifts in time likely track larger scale annual fluctuations in prevailing weather conditions. The prescribed fires on transects 4 and 5 likely also had impacts through time, particularly in the intermediate and higher elevation communities. In only one instance, there was an additional, marginally significant time x storm surge frequency term in the model (Transect #4: Figure 9, Table 5). In this case, shifts due to storm surge treatment effects were not uniformly directional and appear to be driven by species-specific mortality and reduced abundance.

Overall, the lack of surge treatment effects suggests that these communities appear to be largely resilient to the experimental perturbations applied. This finding is contrary to the original hypothesis that inland assemblages would be more “ecologically naïve” and therefore vulnerable to the effects of saline intrusions. There are several reasons why the results do not support the predictions. The volume and residence time of the experimental storm surge may have been insufficient to produce detectable changes in the biota. Also, the soil conditions at the time of the surges likely influenced the longevity of effects and limited the impacts to the community. For example, the low elevation plots were often saturated or had some standing water at the time the surges were applied, which likely diluted the salinity and effect of the treatments. In addition, frequent afternoon thunderstorms were common during the period in which surges were implemented, which may have further diluted the salinity levels following treatments. Similarly, with naturally occurring tropical storms and hurricanes, intense levels of precipitation can ameliorate and limit effects of high salinity storm surges (Edmiston et al. 2008).

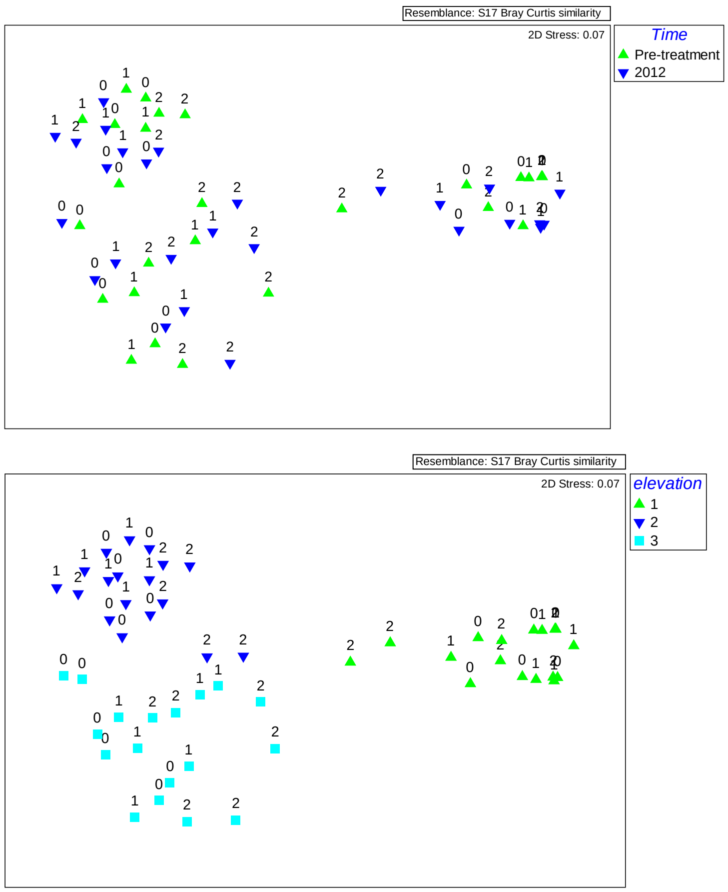


Figure 6. Two-dimensional NMDS ordinations of the Experiment #1 plots along transect #1 (most seaward) through time. Composition of the pre-treatment communities (2009) is included, along with the 2011 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 2. Results of repeated measures PERMANOVA on plots from Experiment #1, arrayed along the most seaward transect (1). Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2009 plots (pre-treatment) and the 2012 plots (2 years following the 2nd surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	4965.1	4965.1	4.4741	0.001
el	2	84460	42230	10.25	0.001
tr	2	8036	4018	0.97524	0.471
Tixel	**2**	**7713.4**	**3856.7**	**3.4753**	**0.001**
Tixtr	2	2068.9	1034.4	0.93215	0.551
elxtr	4	14410	3602.5	0.87438	0.721
ob(elxtr)	18	74160	4120	3.7126	0.001
Tixelxtr	4	3925.2	981.3	0.88427	0.667
Res	18	19975	1109.7		
Total	53	2.1971E5			

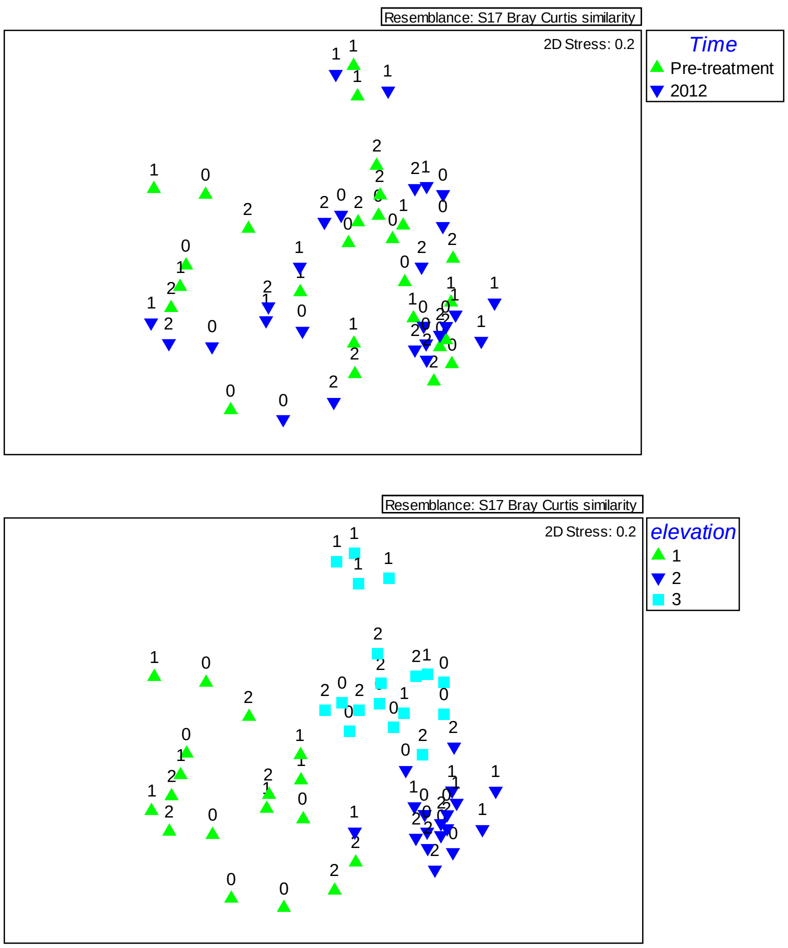
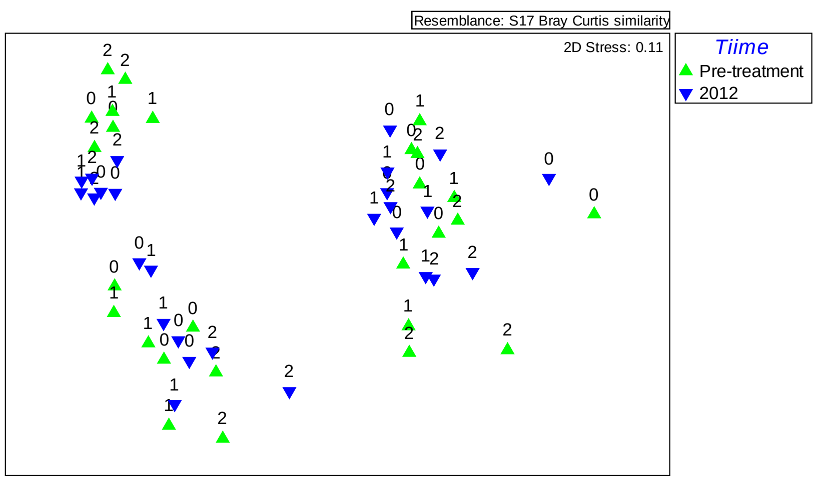


Figure 7. Two-dimensional NMDS ordination of the Experiment #1 plots along transect #2 through time. Composition of the pre-treatment communities (2009) is included, along with the 2011 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 3. Results of PERMANOVA on plots from Experiment #1, arrayed along transect 2. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2009 plots (pre-treatment) and the 2012 plots (2 years following the 2nd surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	11227	11227	9.0633	0.001
el	2	57782	28891	8.9084	0.001
tr	2	6884.7	3442.4	1.0614	0.361
Tixel	**2**	**11234**	**5617.2**	**4.5346**	**0.001**
Tixtr	2	2701.1	1350.5	1.0902	0.35
elxtr	4	12358	3089.6	0.95264	0.556
ob(elxtr)	18	58376	3243.1	2.6181	0.001
Tixelxtr	4	3211.7	802.93	0.64818	0.911
Res	18	22297	1238.7		
Total	53	1.8607E5			



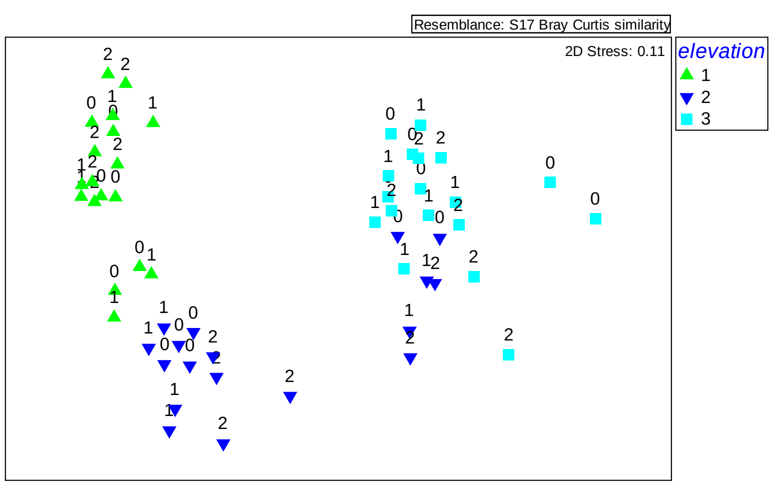
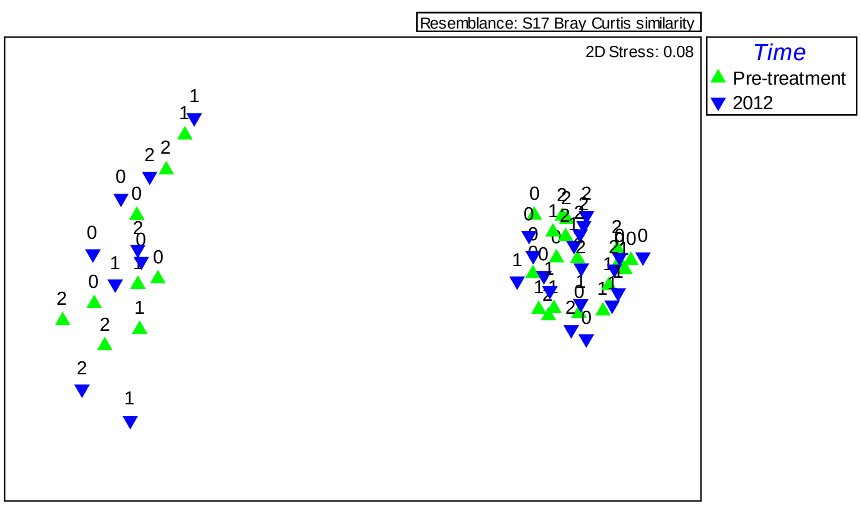


Figure 8. Two-dimensional NMDS ordination of the Experiment #1 plots along transect #3 through time. Composition of the pre-treatment communities (2009) is included, along with the 2011 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 4. Results of PERMANOVA on plots from Experiment #1, arrayed along transect 3. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2009 plots (pre-treatment) and the 2012 plots (2 years following the 2nd surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	4081.6	4081.6	4.3337	0.001
el	2	70964	35482	7.5905	0.001
tr	2	6116.7	3058.3	0.65425	0.872
Tixel	**2**	**5348.4**	**2674.2**	**2.8394**	**0.001**
Tixtr	2	1886.6	943.29	1.0015	0.481
elxtr	4	10990	2747.6	0.58778	0.988
ob(elxtr)	18	84142	4674.5	4.9632	0.001
Tixelxtr	4	2389.4	597.36	0.63424	0.965
Res	18	16953	941.84		
Total	53	2.0287E5			



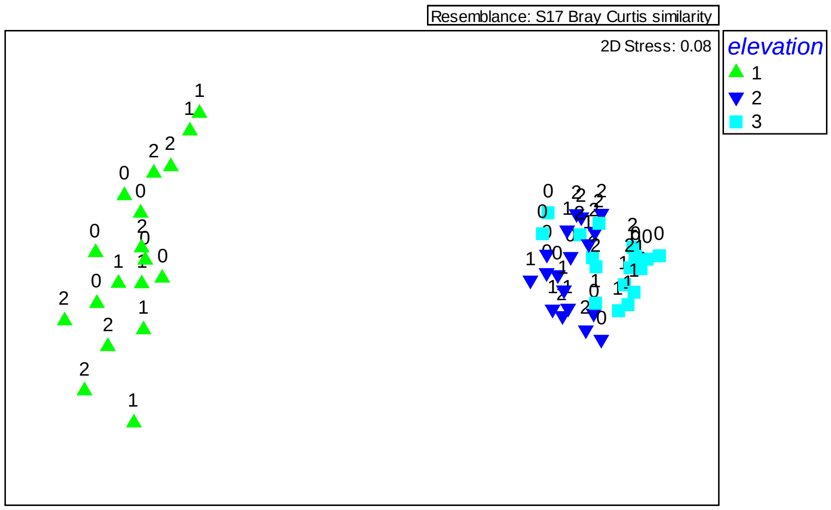


Figure 9. Two-dimensional NMDS ordination of the Experiment #1 plots along transect #4 through time. Composition of the pre-treatment communities (2009) is included, along with the 2011 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 5. Results of PERMANOVA on plots from Experiment #1, arrayed along transect 4. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2009 plots (pre-treatment) and the 2012 plots (2 years following the 2nd surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	5596.3	5596.3	8.4939	0.001
el	2	75727	37863	12.378	0.001
tr	2	4832.5	2416.2	0.78991	0.766
Tixel	**2**	**6600.8**	**3300.4**	**5.0092**	**0.001**
Tixtr	**2**	**2003.1**	**1001.5**	**1.5201**	**0.057**
elxtr	4	11459	2864.8	0.93656	0.611
ob(elxtr)	18	55060	3058.9	4.6426	0.001
Tixelxtr	4	3226	806.49	1.2241	0.159
Res	18	11860	658.87		
Total	53	1.7636E5			

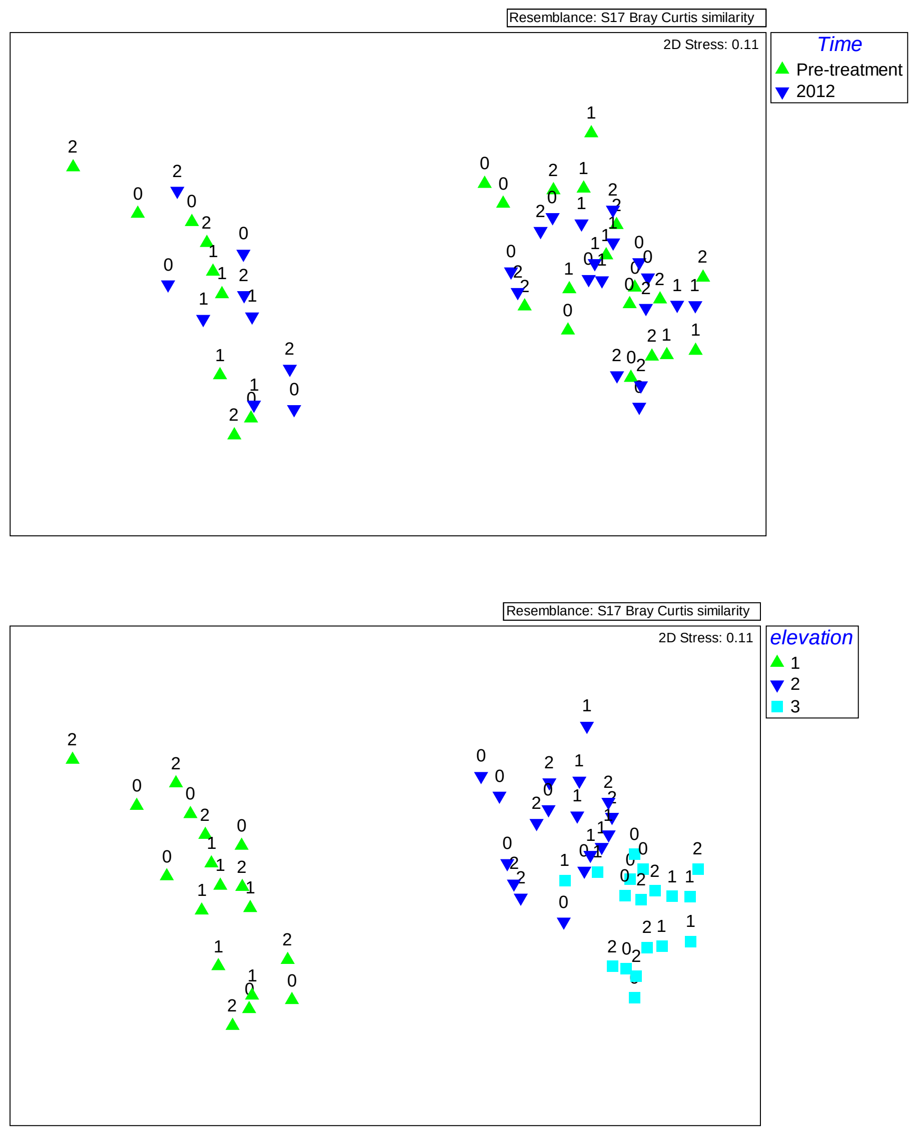


Figure 10. Two-dimensional NMDS ordination of the Experiment #1 plots along transect #5 (most inland) through time. Composition of the pre-treatment communities (2009) is included, along with the 2011 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

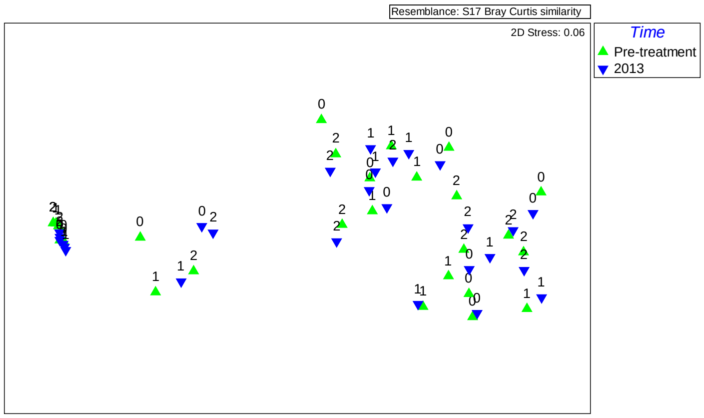
Table 6. Results of PERMANOVA on plots from Experiment #1, arrayed along the most inland transect (5). Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2009 plots (pre-treatment) and the 2012 plots (2 years following the 2^{nd} surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	4582	4582	6.2665	0.001
el	2	75766	37883	11.022	0.001
tr	2	5660.8	2830.4	0.82351	0.74
Tixel	**2**	**5965.8**	**2982.9**	**4.0795**	**0.001**
Tixtr	2	982.27	491.13	0.67169	0.905
elxtr	4	11181	2795.2	0.81326	0.841
ob(elxtr)	18	61866	3437	4.7006	0.001
Tixelxtr	4	2898.6	724.64	0.99106	0.506
Res	18	13161	731.18		
Total	53	1.8206E5			

Experiment #2: Community Responses to Experimental Storm Surge and Propagule Additions.

In contrast to the previous study, there were significant effects of storm surge treatments on the plant community composition. This experiment was different from the previous one in that it was initiated a year following the previous one and therefore covers a different four-year time period following the initial surge (2010-2013). Also, propagules were added to plots and the second surge event was double the volume of the first.

Along the first transect, there was a significant time x elevation interaction, indicating that the three elevation zones changed differently over the four-year time period (Table 7, Figure 11). There was also a marginally significant time x surge frequency interaction; this effect indicates that composition responded differently, depending on the number of surges the plots received. Composition changed over the four-year period, and the trajectories differed depending on the storm surge frequency treatment received. There were a number of significant indicator species (Table 12); these species were constant and faithful to particular elevation/surge frequency combinations. The only species that was an indicator of the double-surge treatment was the brackish marsh dominant, *Juncus roemerianus*. The remaining species were indicators of the control plot conditions (i.e., presumably salt-sensitive) or the single-surge treatment.



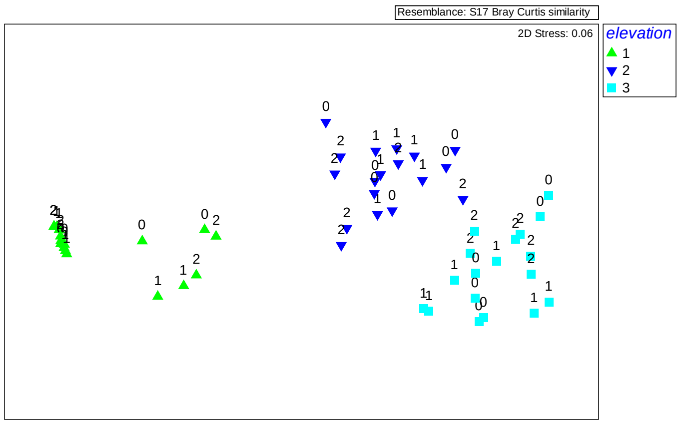


Figure 11. Two-dimensional NMDS ordinations of the Experiment #2 plots along transect #1 (most seaward) through time. Composition of the pre-treatment communities (2010) is included, along with the 2013 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2013 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

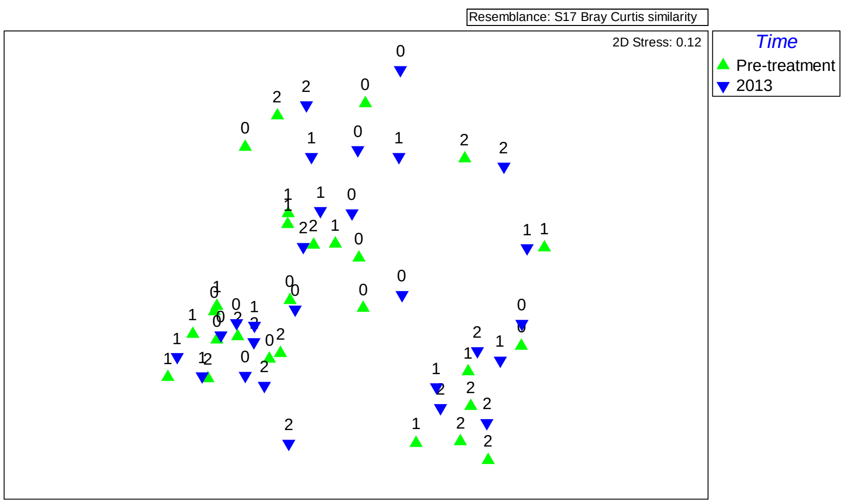
Table 7. Results of repeated measures PERMANOVA on plots from Experiment #2, arrayed along the most seaward transect (1). Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2010 plots (pre-treatment) and the 2013 plots (2 years following the 2^{nd}, double-volume surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	2345	2345	4.9315	0.001
el	2	92416	46208	10.172	0.001
tr	2	6008.5	3004.2	0.66133	0.91
Tixel	**2**	**3666.5**	**1833.3**	**3.8553**	**0.001**
Tixtr	**2**	**1510.9**	**755.47**	**1.5887**	**0.065**
elxtr	4	11953	2988.4	0.65784	0.97
ob(elxtr)	18	81769	4542.7	9.5532	0.001
Tixelxtr	4	2395.1	598.77	1.2592	0.158
Res	18	8559.3	475.52		
Total	53	2.1062E5			

Along transects 2 and 3, there were significant time x elevation x surge frequency interactions (Tables 8 and 9). This higher order interaction indicates an influence of the surge treatments that differed, depending on the elevation zone, and an overall before *vs*. after surge treatment difference. Based on the ordinations, the plots receiving a second surge appeared to diverge moreso over the four-year period than the control and 1x surge plots (Figures 12 and 13). These changes were driven by both changes in relative abundances of species with declines in the most species most sensitive to the saline surges. In some cases, there were local losses of species, particularly in the double-volume, second surge communities.

There were 14 significant indicator species along transect 2, and interestingly, 5 of these were in the low elevation zone plots that received the double-surge treatment (Table 13). This result was somewhat unexpected, as many of these species are freshwater obligate or facultative species and not considered tolerant of saline conditions. It is possible, however, that the ambient moisture conditions in this zone diluted the surges to the point that these species were capable of surviving those treatments and thriving over time. Species in this position along the estuarine gradient (Figure 1) may be infrequently exposed to dilute pulses of saline water, depending on tidal influence, occasional droughts, on-shore winds, and tropical storms.

Along transect 3, there were 15 indicator species, but only one was an indicator of the double-surge treatment (Table 14). There were a number of obligate and facultative freshwater wetland species in the low elevation zone that were indicators of the single-surge treatment, suggesting tolerance of some species to infrequent (and likely dilute) salinity pulses.



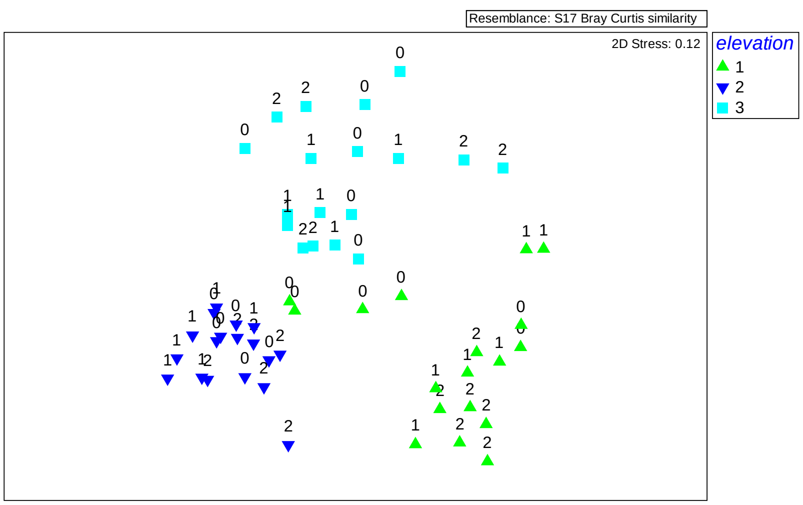
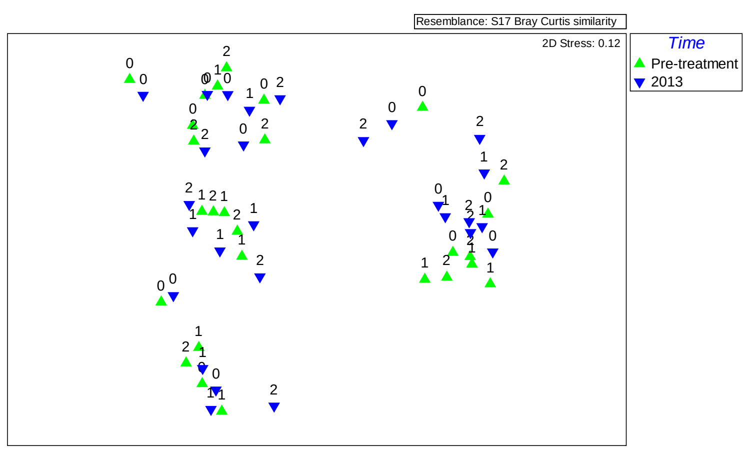


Figure 12. Two-dimensional NMDS ordination of the Experiment #2 plots along transect #2 through time. Composition of the pre-treatment communities (2010) is included, along with the 2012 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 8. Results of repeated measures PERMANOVA on plots from Experiment #2, arrayed along transect 2. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2010 plots (pre-treatment) and the 2013 plots (2 years following the 2nd, double-volume surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	3164.6	3164.6	4.5055	0.002
el	2	75650	37825	8.8696	0.001
tr	2	10121	5060.5	1.1866	0.234
Tixel	2	3417.6	1708.8	2.4329	0.001
Tixtr	2	2164.5	1082.3	1.5408	0.06
elxtr	4	21717	5429.2	1.2731	0.118
ob(elxtr)	18	76762	4264.5	6.0716	0.001
Tixelxtr	**4**	**4954.6**	**1238.6**	**1.7635**	**0.007**
Res	18	12643	702.38		
Total	53	2.1059E5			



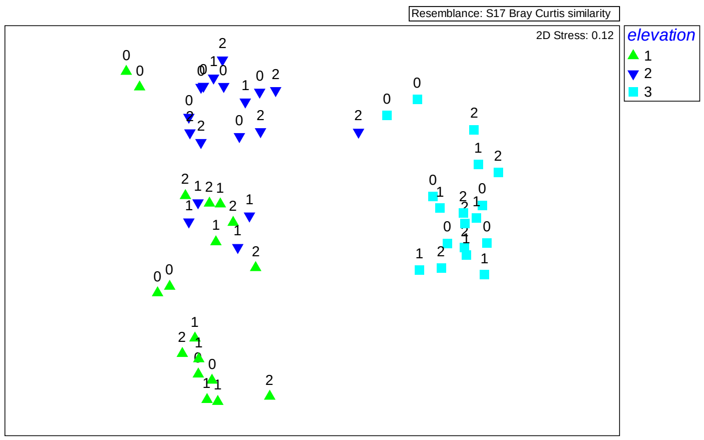


Figure 13. Two-dimensional NMDS ordination of the Experiment #2 plots along transect #3 through time. Composition of the pre-treatment communities (2010) is included, along with the 2012 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 9. Results of repeated measures PERMANOVA on plots from Experiment #2, arrayed along transect 3. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2010 plots (pre-treatment) and the 2013 plots (2 years following the 2nd, double-volume surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	4359.6	4359.6	8.9018	0.001
el	2	73163	36581	9.6324	0.001
tr	2	6979.4	3489.7	0.91889	0.572
Tixel	2	4629.5	2314.8	4.7265	0.001
Tixtr	2	2393.2	1196.6	2.4434	0.009
elxtr	4	14920	3730	0.98215	0.503
ob(elxtr)	18	68360	3797.8	7.7546	0.001
Tixelxtr	**4**	**3575.9**	**893.97**	**1.8254**	**0.013**
Res	18	8815.3	489.74		
Total	53	1.872E5			

Composition of plant communities along transect 4 were influenced by the storm surge frequency treatment and by a time x elevation interaction (Table 10). There was very little separation between the intermediate and high elevation zones (Figure 14). In these plots, the understory was dominated by wiregrass that appeared largely resilient to the storm surge treatments and a mixture of other grasses and forbs that increased in abundance after the more sensitive species declined (e.g., *Aster chapmanii*; Table 15). The two prescribed fires that occurred in these zones (2011 and 2013) also had a dramatic impact on the herbaceous layer that could not be teased apart from the treatment effects. In general, the fires reduced cover of the dominant wiregrass and woody shrub species that typically encroach in pine savannah habitat (e.g., *Cyrilla racemiflora*). Although the herbaceous layer had rebounded in cover by the end of the seasons in which prescribed fire occurred, the fires likely drove more persistent shifts in community composition.

The low elevation communities were more varied in composition and also shifted slightly, albeit not in a consistent direction with the different surge frequency treatments. These communities generally had very low ground cover prior to the surges; in some cases, the overall cover was < 5% following surge treatments. There were few species with low cover in these assemblages, which limited response trajectories following the treatments.

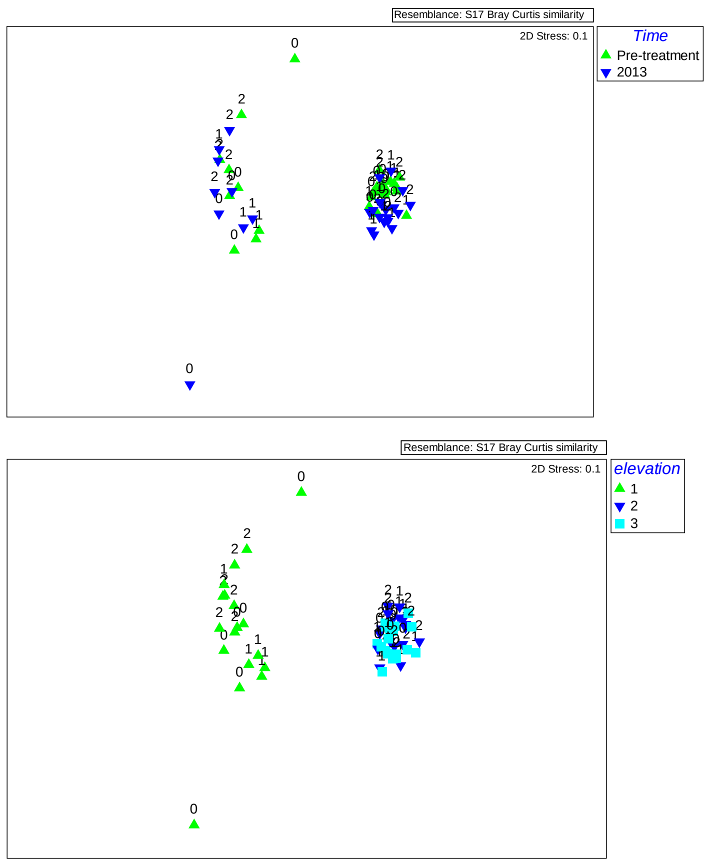


Figure 14. Two-dimensional NMDS ordination of the Experiment #2 plots along transect #4 through time. Composition of the pre-treatment communities (2010) is included, along with the 2012 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

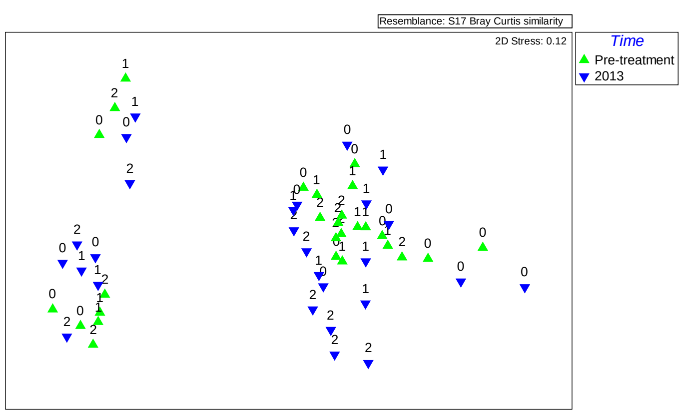
Table 10. Results of repeated measures PERMANOVA on plots from Experiment #2, arrayed along transect 4. Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2010

plots (pre-treatment) and the 2013 plots (2 years following the 2nd, double-volume surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	6951.6	6951.6	9.9169	0.001
el	2	59410	29705	12.186	0.001
tr	**2**	**8197**	**4098.5**	**1.684**	**0.023**
Tixel	**2**	**5430.3**	**2715.1**	**3.8733**	**0.001**
Tixtr	2	2100.1	1050	1.4979	0.104
elxtr	4	11852	2962.9	1.2126	0.157
ob(elxtr)	19	47115	2479.7	3.5375	0.001
Tixelxtr	4	2596.4	649.1	0.92598	0.573
Res	17	11917	700.99		
Total	53	1.6647E5			

Composition along the most inland transect (5) was affected by significant interactions between time x elevation and time x surge frequency (Table 11). Some changes were evident in zones across the four-year study period. The high elevation plots that received a double-surge had the most obvious separation (Figure 15). Many of these plots still had very low vegetation cover in the final year of the surveys (2013) and in subsequent visits to these sites in 2014. These compositional changes are driven largely by declines in abundance of the most salt-sensitive species (i.e., the losers) and limited increases in abundance of the survivors (i.e., the winners).

Given that propagules of species from seaward locations were introduced to all plots in this experiment, some upslope/inland establishment of these species was expected when experimental storm surge sufficiently disturbed the extant vegetation. The second, double-volume storm surge drove major changes in the composition and cover of those plots, but no “upslope migrants” were documented in the surveys. Successful colonization of seaward species during these windows of opportunity is likely to depend on the length of time these openings persist, but may also require multiple, recurrent additions of propagules such that suitable environmental conditions and germination cues coincide.



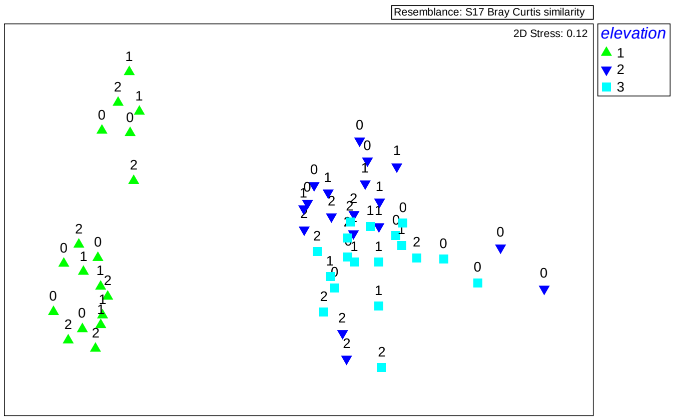


Figure 15. Two-dimensional NMDS ordination of the Experiment #2 plots along the most inland transect (5) through time. Composition of the pre-treatment communities (2010) is included, along with the 2012 communities (following two years after the second surge treatment). In the upper panel, plots are coded by pre-treatment vs. 2012 composition and by storm surge frequency (0, 1, and 2). In the bottom panel, plots are coded numerically by elevation (1, 2, and 3m) on the ordination graph. The ordination is based upon percent cover of all vascular plant species recorded.

Table 11. Results of repeated measures PERMANOVA on plots from Experiment #2, arrayed along the most inland transect (5). Terms in the models included time (ti), elevation (el), and storm surge frequency (tr). The two time levels in the model differentiate between composition of the 2010 plots (pre-treatment) and the 2013 plots (2 years following the 2^{nd}, double-volume surge treatment).

Source	df	SS	MS	Pseudo-F	P
Ti	1	10014	10014	13.42	0.001
el	2	62438	31219	8.5973	0.001
tr	2	7736.7	3868.3	1.0653	0.37
Tixel	**2**	**7823.3**	**3911.6**	**5.2419**	**0.001**
Tixtr	**2**	**3499.2**	**1749.6**	**2.3446**	**0.008**
elxtr	4	9459.3	2364.8	0.65124	0.958
ob(elxtr)	18	65363	3631.3	4.8661	0.001
Tixelxtr	4	3546.9	886.72	1.1883	0.233
Res	18	13432	746.23		
Total	53	1.8331E5			

Overall, the Indicator Species Analysis revealed sets of species that were likely sensitive to the storm surges in that they were significant indicators of control plots (Tables 12-16). The analysis also pointed to species that were more resilient or even perhaps even opportunistic at taking advantage of the post-surge conditions; these species were indicators of one or the other surge frequency treatment. Indicators of the single or the double surge did not appear to be ones that had migrated from downslope following the disturbances, but rather ones that were resilient to the surges. Downslope species that were added (*Spartina alterniflora*, *Juncus roemerianus*, *Baccharis halimifolia*) did not establish in upslope communities, even in surge plots. It is possible that seed germination requirements were not met in these new locations, but it remains unclear whether those seeds became incorporated into the seed bank and may establish in future. Although some live *Spartina alterniflora* culms were observed at the end of the 2010 growing season, none were present by the following 2011 growing season survey. The prescribed fires that impacted Transects #4 and 5 may have limited germination of species added, as well as survival of *Spartina* transplants.

Several of the indicator species were also ones that had been selected as propagule additions, e.g., *Juncus roemerianus* and *Andropogon glomeratus*. None of these appeared in elevation zones where they were not present already, rendering it impossible to determine whether their establishment in the vegetation was from the additions, local dispersal from neighboring individuals, or recruitment from the seed bank.

Table 12. Indicator values for species in plots on Transect #1 in Experiment #2 that are statistically significant indicators of elevation and storm surge treatment groups. P values < 0.1 are considered significant and are based on permutations.

	1 m Elevation			**2 m Elevation**			**3 m Elevation**			
Species	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**p**
Juncus roemerianus			39							0.07
Chasmanthium laxum				39						0.02
Cyrilla racemiflora					60					0.04
Woodwardia virginiana						47				0.09
Serenoa repens							85			0.01
Andropogon virginicus							55			0.08
Vaccinium arboreum							45			0.04
Pinus elliottii								62		0.01
Quercus virginiana								57		0.08
Dichanthelium ensifolium								52		0.02

Table 13. Indicator values for species in plots on Transect #2 in Experiment #2 that are statistically significant indicators of elevation and storm surge treatment groups. P values < 0.1 are considered significant and are based on permutations.

	1 m Elevation			**2 m Elevation**			**3 m Elevation**			
Species	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**p**
Hypericum spp.		53								0.09
Rhynchospora corniculata		38								0.09
Rhynchospora cephalantha			93							0.01
Juniperus virginiana			67							0.07
Smilax laurifolia			58							0.02
Eriocaulon decangulare			51							0.07
Carex glaucescens			49							0.03
Gaylussacia mosieri				62						0.02
Ilex coriacea				57						0.003
Cliftonia monophylla					48					0.08
Quercus hemispherica							67			0.03
Quercus geminata								57		0.02
Ilex glabra								37		0.09
Andropogon virginicus									67	0.08

Table 14. Indicator values for species in plots on Transect #3 in Experiment #2 that are statistically significant indicators of elevation and storm surge treatment groups. P values < 0.1 are considered significant and are based on permutations.

	1 m Elevation			**2 m Elevation**			**3 m Elevation**			
Species	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**p**
Lobelia floridana		67								0.08
Oxypolis filiformis		56								0.02
Rhynchospora cephalantha		53								0.08
Dulichium arundinaceum		52								0.08
Sarracenia leucophylla		50								0.02
Lachnocaulon anceps		45								0.02
Smilax laurifolia		45								0.03
Rhynchospora gracilenta			42							0.06
Lyonia lucida				43						0.001
Drosera brevifolia					67					0.08
Andropogon virginicus					56					0.08
Licania michauxii							67			0.08
Tragia smallii							53			0.08
Quercus geminata							37			0.05
Andropogon glomeratus								43		0.08

Table 15. Indicator values for species in plots on Transect #4 in Experiment #2 that are statistically significant indicators of elevation and storm surge treatment groups. P values < 0.1 are considered significant and are based on permutations.

	1 m Elevation			**2 m Elevation**			**3 m Elevation**			
Species	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**p**
Carex glaucescens		38								0.08
Chasmanthium ornithorhynchum			70							0.01
Cliftonia monophylla				67						0.08
Panicum virgatum				51						0.08
Lachnocaulon caroliniana						34				0.03
Hypericum sp.							54			0.03
Andropogon mohrii							48			0.02
Lachnocaulon anceps							35			0.03
Ilex glabra							30			0.03
Schizachyrium scoparium							22	50		0.08
Aster chapmanii									67	0.08
Scleria sp.									67	0.08

Table 16. Indicator values for species in plots on Transect #5 in Experiment #2 that are statistically significant indicators of elevation and storm surge treatment groups. P values < 0.1 are considered significant and are based on permutations.

	1 m Elevation			2 m Elevation			3 m Elevation			
Species	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**Control**	**1x surge**	**2x surge**	**p**
Ilex myrtifolia		67								0.08
Rubus betufolius		43								0.08
Carex glaucescens		39								0.08
Rhynchospora cephalantha			65							0.01
Hypericum sp.				67						0.08
Arundinaria tecta					54					0.03
Rhexia alifanus					47					0.04
Dichanthelium tenue						51				0.04
Seriocarpus tortifolius							100			0.004
Pityopsis graminifolia							84			0.007
Carphephorus odoratus							62			0.02
Schizachyrium scoparium							50			0.07
Lobelia brevifolia									57	0.07

Experiment #3: Storm Surge + Sediment Deposition.
Analyses of initial mortality data revealed differential susceptibility to the combined disturbances with respect to elevation. Not surprisingly, mortality and soil water conductivity did not differ between control and surge treatments at the most seaward transect (Table 17) as species along this transect are generally more tolerant to and more often exposed to tidal and storm influences. In plots along the remaining four transects, mortality was always significantly higher in surge treatments compared to controls. Soil water conductivity, however, was not consistently higher in the treated plots, indicating that the abiotic imprint of these pulses can be ephemeral, despite the effects on the plant community. Because the plots adjacent to the river were often slightly flooded, it is likely that the surge treatment was quickly diluted. Also, the storm surge infiltrated quickly in the highest elevation plots that are underlain by deep sands.

In general, vegetation appeared to sustain greater damage and disassembly than plots that received storm water alone (Experiments #1 and 2). The combination of saline water and sediment burial drove patterns of high mortality across the estuarine gradient (Figures 16 and 17). Many of the plants that were buried appeared to be dead upon the second visit to the plots. With the exception of several plots that are inundated periodically by East River, the majority of plots remained covered by a 5 cm sediment layer of sand and silt until the end of the study. The effects of the storm surge may be muted or accentuated, however, depending on the existing environmental conditions. Mortality was highly variable and likely depends upon the type of vegetation present and local soil conditions (**Appendix** 1). For example, mortality was estimated as 0% for the low elevation plots along transect #4; this community is a forested wetland with a shaded, sparse understory that had often has standing water.

The long-term trends in composition indicate dramatic changes in composition with surge/sediment treatments. With the exception of brackish/salt marsh communities at the edge of East Bay (omitted from Figure 18 due to disjunction in the ordination; comparisons to control plots depicted in Figure 19), the treated plots strongly diverged from the controls. Dissimilarity of treated vs. control plots across all transects was high and these patterns persisted throughout the study period (Figures18-27). Community composition diverged, primarily due to differential loss of species from the assemblages.

Although the expectation was that highly disturbed plots would be prime establishment sites for upslope migration, the changes in community structure did not include establishment of downslope species. Instead, disturbed assemblages remained relatively depauperate in species richness and low in vegetation cover. The communities did continue to shift over the course of the study and were still changing in 2013 when the study concluded. Shifts were driven mainly by slight changes in abundance of survivors, and limited "new" invaders from the surrounding, local species pool. These results suggest that vegetation recovery is slow where the surge disturbance is highly intense. Low resilience and delayed recovery, or lack thereof, provide longer windows of opportunity for new species to invade and establish. The temporal span of these "regeneration windows" is thus likely to be critical for successful migration of species that are slow to arrive due to dispersal limitation or spatial separation from what are otherwise suitable inland establishment sites.

The effects of prescribed fire on the upslope communities of Transects #4 and 5 could not be isolated from surge impacts to the communities. However, in each of the impacted elevation zones (2m and 3m), the control plots and their respective surge plots were similarly burned. Therefore, they were treated identically, with the exception of the surge treatment effects. Assemblages that experience double, *and different*, disturbances may be indeed have broader "regeneration windows" for migrating species to colonize.

Sediment mixtures that were added to the storm surge slurry for these treatment applications were composed of material from East River and East River Bay. It it is possible that seeds and other propagules may have been inadvertently included when this material was collected, although I am confident that this material was not a source for "off-site" species establishment in the plots. The sand and silt material was excavated underwater, and all excavation sites were not vegetated. Also, the survey data indicated no establishment of "off-site" species in any of the plots.

Table 17. Summarized results of the two-way ANOVA and Tukey's pairwise means comparisons for soil water conductivity and short-term plant mortality from storm surge experiment #1. In both cases, the interaction terms were not significant and are therefore not

included here. Results of the Tukey's tests are only included when the ANOVA results warranted *a posteriori* comparisons. All analyses were performed using SAS, version 9.12.

	Soil Water Conductivity (µS)		**Percent Plant Mortality (%)**	
Estuarine Gradient Position (seaward to landward)	Treatment (control and surge)	Elevation Zone (lower, middle, and upper)	Treatment (control and surge)	Elevation Zone (lower, middle, and upper)
1	ns	*Lower zone greater than others	ns	ns
2	ns	ns	*Greater in surge plots	ns
3	*Greater in surge plots	*Middle zone greater than upper	*Greater in surge plots	*Lower zone less than middle
4	ns	ns	*Greater in surge plots	*Lower zone less than middle
5	*Greater in surge plots	ns	*Greater in surge plots	ns

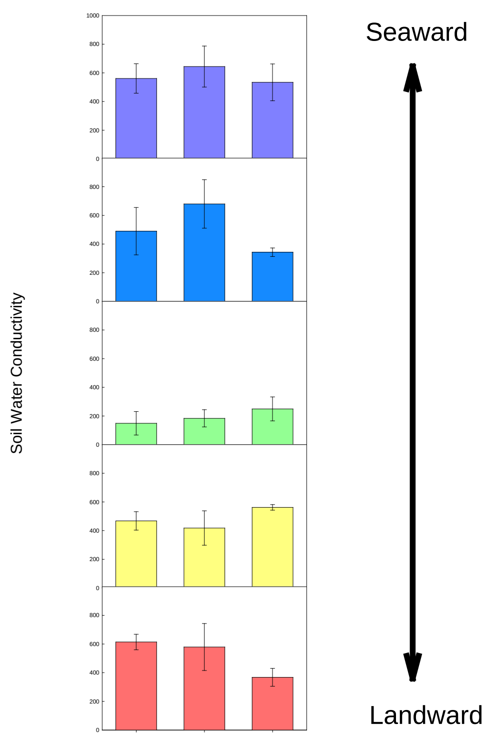


Figure 16. Soil water conductivity profile one month following the 2010 surge.

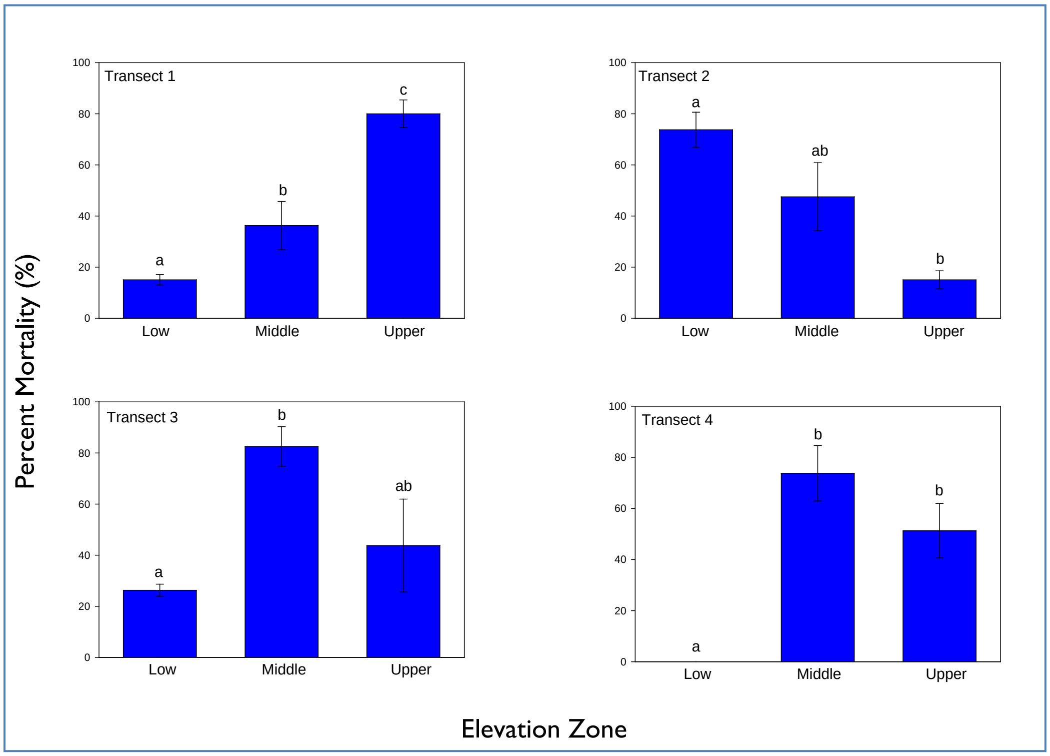


Figure 17. Average percent mortality of vegetation across the East River estuarine gradient; these plots were treated with storm surge + sediment. Each transect was analyzed separately. There were significant differences among elevation zones for transects 1-4. Mortality did not differ by elevation zone for transect 5, but was high overall and averaged 76.67 ± 7.79 (SE). Results of the Tukey's tests are only included when the ANOVA results warranted *a posteriori* comparisons.

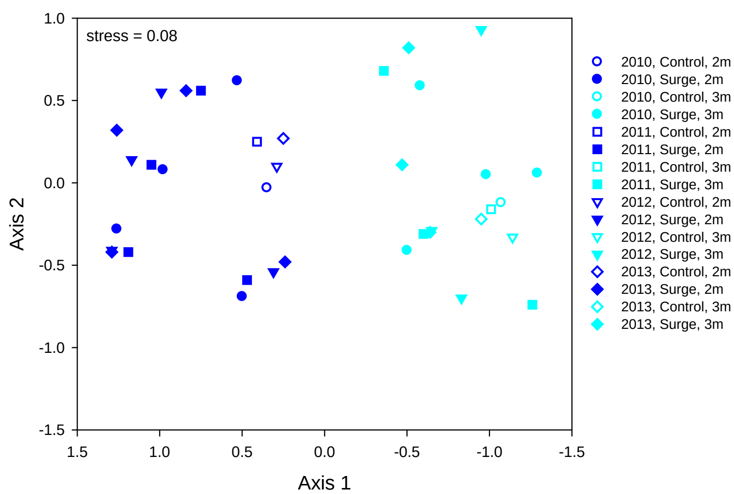


Figure 18. Non-metric multidimensional scaling ordination of storm surge + sediment plots arrayed along the most seaward transect (#1). Note that the 1m salt marsh plots, which were almost exclusively dominated by *Juncus roemerianus*, were excluded from this NMDS ordination due to a disjunction in community composition.

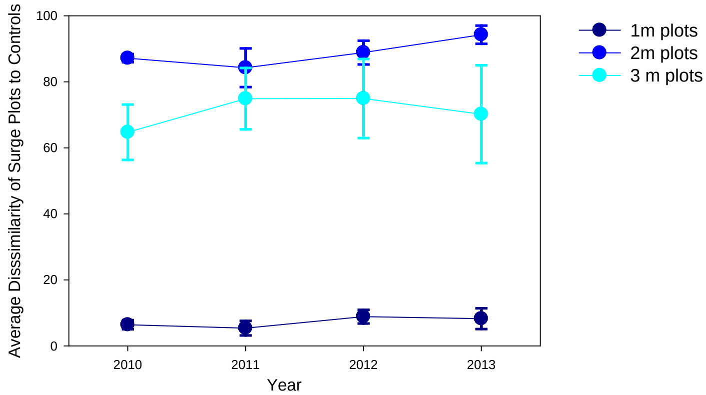


Figure 19. Average community dissimilarity between control *vs*. surge + sediment plots through time along the most seaward transect (#1).

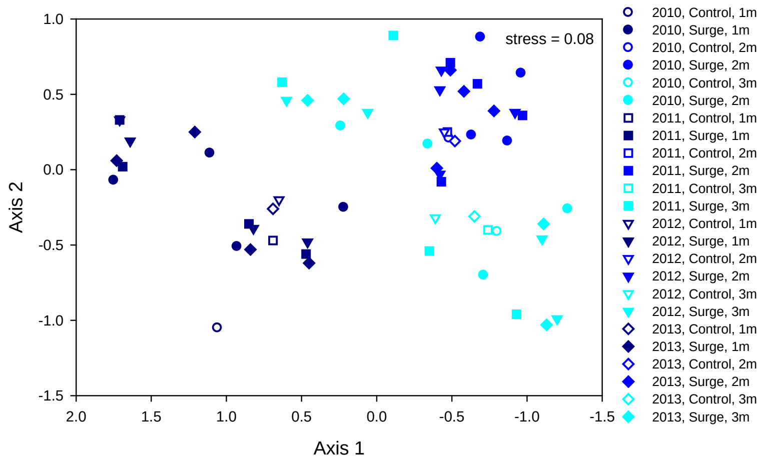


Figure 20. Non-metric multidimensional scaling ordination of storm surge + sediment plots arrayed along transect #2.

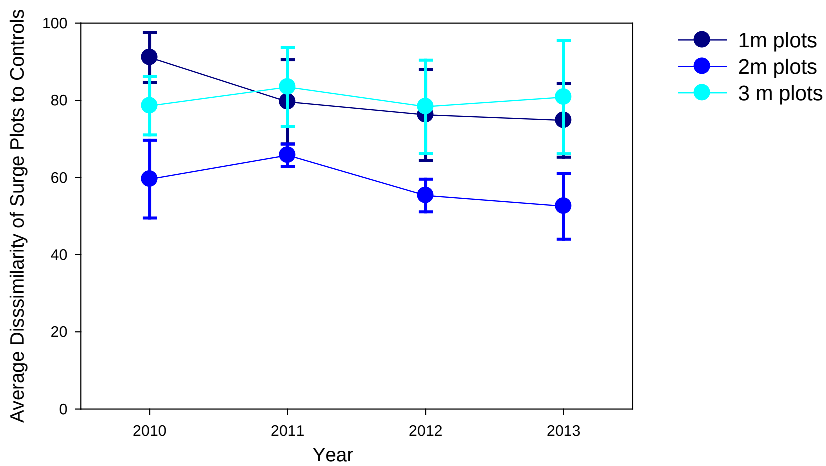


Figure 21. Average community dissimilarity between control *vs*. surge + sediment plots through time along transect #2.

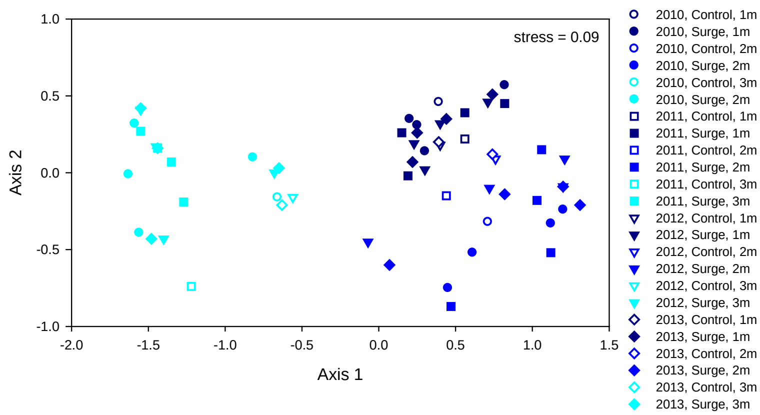


Figure 22. Non-metric multidimensional scaling of storm surge + sediment plots arrayed along transect #3.

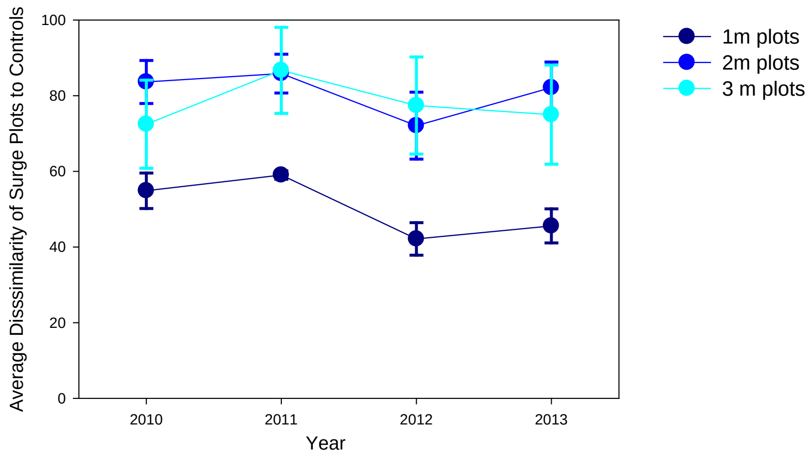


Figure 23. Average community dissimilarity between control *vs*. surge + sediment plots through time along transect #3.

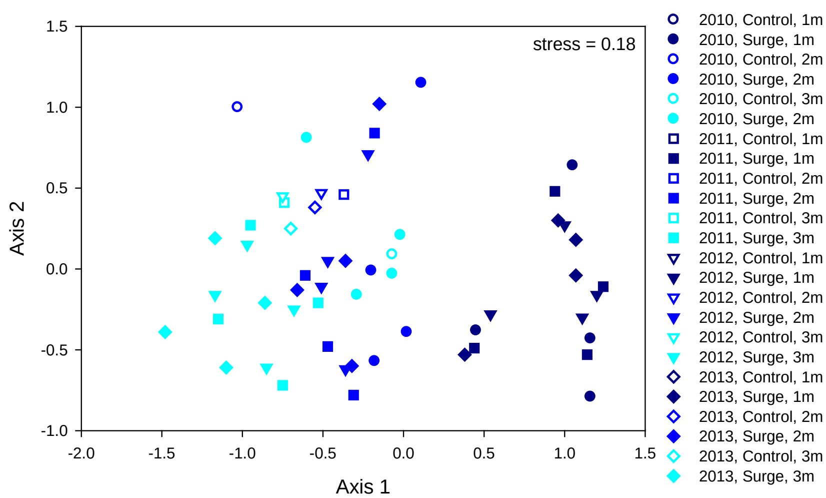


Figure 24. Non-metric multidimensional scaling of storm surge + sediment plots arrayed along transect #4.

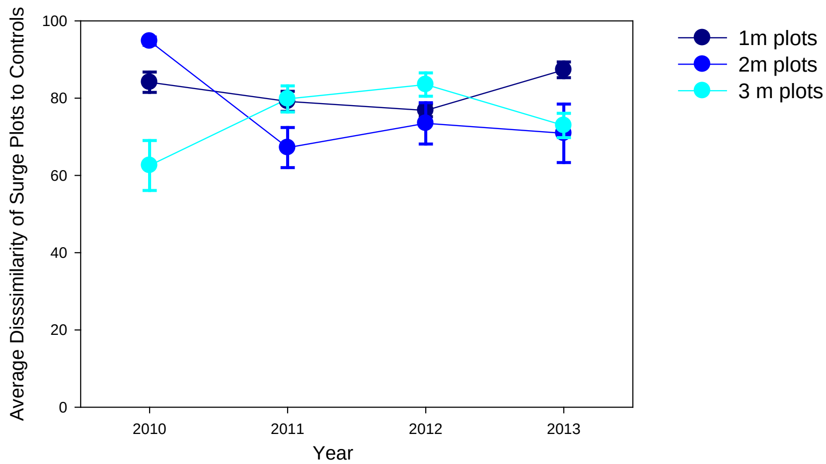


Figure 25. Average community dissimilarity between control *vs*. surge + sediment plots through time along transect #4.

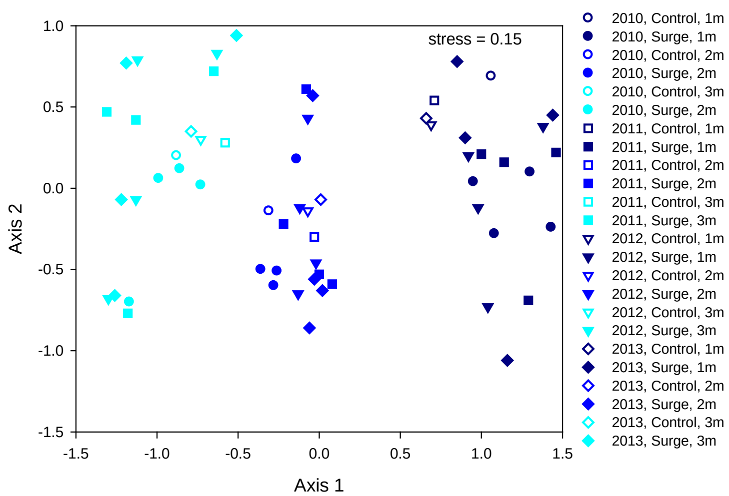


Figure 26. Non-metric multidimensional scaling of storm surge + sediment plots arrayed along the most inland transect (#5).

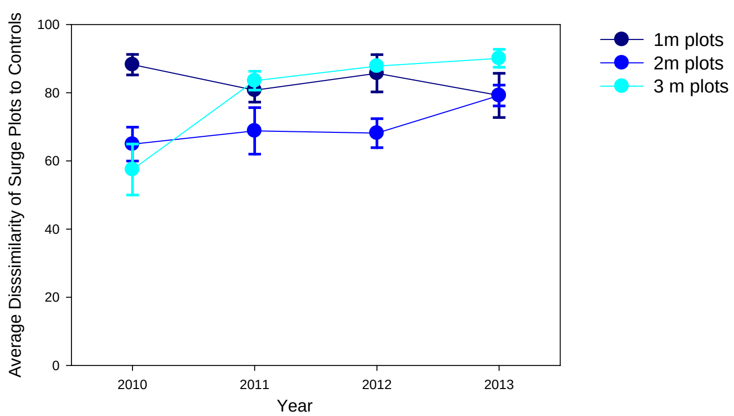


Figure 27. Average community dissimilarity between control *vs*. surge + sediment plots through time along the most inland transect (#5).

Experiment #4: Habitat Modification and Assisted Migration.
Results of this reciprocal transplant study were clear, conclusive, and also contained some surprises. The expectation was that transplanted species would have greater survival in plots where would-be competitors had been removed. Previous work in other estuarine communities suggests that competition limits upslope expansion of marsh species (Crain et al. 2004). In this study, initial survival was high for the migrating species (*Cladium mariscus*, *Juncus roemerianus*, and *Spartina alterniflora*) (Figure 28), and there was no indication of a vegetation removal effect (Battaglia, field observations). The "straw man" upslope resident species *Aristida stricta* was not expected to establish anywhere other than the assemblages where it occurs currently. Transplant shock was evident, however, even in pine savanna habitats where it was transplanted (data not shown). A second round of planting was done to be certain that transplanting was done as carefully as possible, and survival of this species was still too low for statistical analyses.

For the other species, the initial survival surveys also indicated that *Spartina* was susceptible to terrestrial herbivory (Figure 28). It is suspected that white-tailed deer and rodents were the main herbivores that influenced survival of this species, although there was also evidence of bear activity in *Spartina* subplots.

At the end of the 2012 growing season, there was no statistical effect of vegetation removal on any of the three species. For each, however, there was a transect x elevation zone interaction that affected survival (*Cladium*, $F = 3.67$, $p < 0.0001$; *Juncus* $F = 3.61$, $p = 0.0063$; *Spartina* $F = 2.54$, $p = 0.0003$). In general, all species had better survival in the wetter zones closest to East River, although they all survived in upslope areas.

By the end of the 2013 growing season, there was a treatment effect for *Cladium* ($F = 8.20$, $p = 0.0051$) where survival was significantly higher (11% vs. 4%) in vegetation removal plots vs. controls. There remained a transect x elevation zone interaction ($F =6 .40$, $p < 0.0001$). *Juncus* ($F = 2.18$, $p = 0.0022$) and *Spartina* ($F = 2.62$, $p = 0.0118$) were still affected by a transect x elevation zone interaction, but there were no vegetation removal effects.

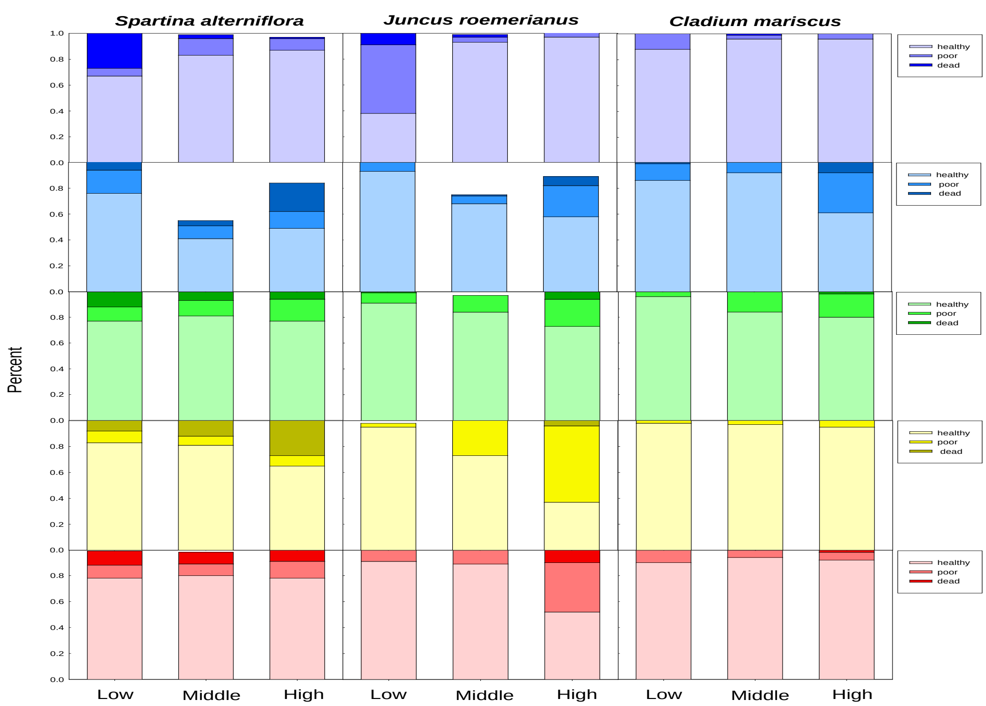
In the final survey of Summer 2014, *Cladium* and *Juncus* survival were positively affected by vegetation removal and the persistent transect x elevation zone interaction (Figures 29: $F = 7.68$, $p < 0.0001$ and Figure 30: $F = 7.16$, $p < 0.0001$)). *Cladium* had higher survival (13% vs. 4%) in treated *vs*. control plots ($F = 3.04$, $p < 0.0001$). *Juncus* also had higher survival (24% vs. 15%) in treated vs. control plots ($F = 6.21$, $p < 0.0001$). *Spartina* survival was apparently affected by a transect x elevation zone x treatment interaction ($F = 4.19$, $p < 0.0001$). Given its exceedingly low survival (< 4% overall; not shown), this statistical result is relatively uninformative and may be spurious.

Survival in the early years of the study was not generally influenced by vegetation removal, and there were some indications based on field observations that neighboring vegetation may have been beneficial to survival of transplants. In some cases, the transplants appeared healthier in control plots (Battaglia, field observations), indicating a potential nurse effect of the surrounding vegetation. In later years, however, the vegetation may have become detrimental to transplant survival as they competed for resources with established plants and led to significantly better survival in removal plots.

In the three migrating species, species survived in their original zone and landward, at least for some period of time. *Spartina* survived initially in all habitats, including upland communities, but appeared susceptible to terrestrial herbivory. The main assemblage where it persisted and spread rhizomatously was the zone just immediately upslope of its salt marsh location. In brackish marsh where *Juncus* dominates, *Spartina* proliferated where its competitor had been removed, suggesting that competition does limit its upslope advancement. *Juncus* had the highest survival of all three across a broad range of conditions. *Cladium* survival was lower to moderate, depending on gradient position and elevation zone.

Although there have been other accounts of *Juncus* and *Cladium* tolerance to fire (Uchytil 1992, Nyman and Chabreck 1995), this study is interesting because it is the first to my knowledge to document tolerance to fire in these two species in upslope transplant locations. These species established and persisted in habitats that were very different in terms of soil moisture, texture, identity of neighbors, but perhaps more interestingly, they survived *multiple* prescribed fires in their new environs. When species are considered for assisted migration, new physical environmental effects must be taken into account to determine the feasibility of success. In addition, species interactions and disturbances that are novel to the migrating species will also influence and perhaps limit success. In this case, these two species are excellent candidates for assisted migration of dominant marsh species in a variety of coastal habitats.

Landward to seaward (Transects 1-5)



Elevation gradient relative to East River

Figure 28. Initial survival and plant condition of *Cladium mariscus*, *Juncus roemerianus*, and *Spartina alterniflora* transplants in early Spring 2012 across the estuarine (vertical axis) and elevation gradients (horizontal axis). The most seaward transect (#1) is color coded in purple, and the most inland transect (#5) is color-coded in red.

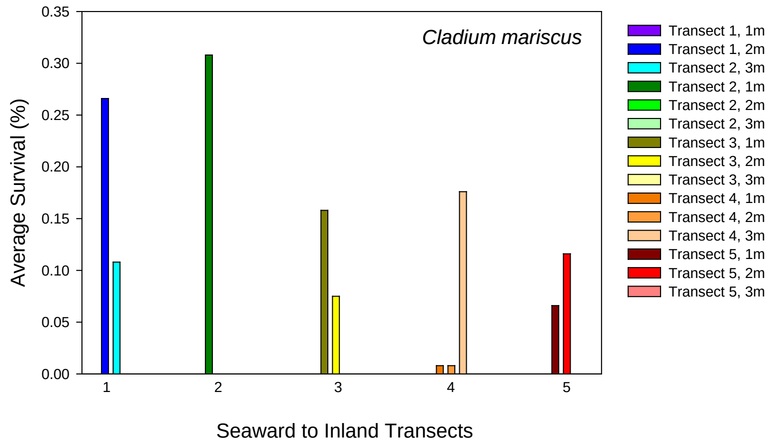


Figure 29. Average survival of *Cladium mariscus* in the final census (Summer 2014) across seaward to inland transects and elevation zones ($F = 3.04$, $p < 0.0001$). The models also indicated that survival was significantly higher in plots with vegetation removal *vs*. controls ($F = 9.76$, $p = 0.0023$).

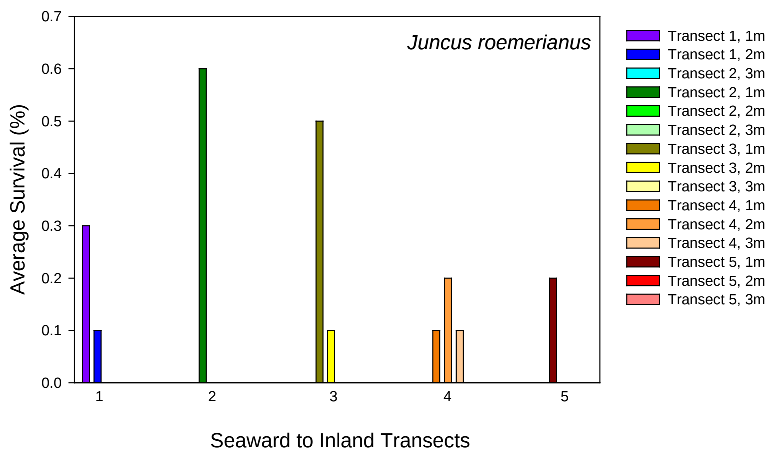


Figure 30. Average survival of *Juncus roemerianus* in the final census (Summer 2014) across seaward to inland transects and elevation zones ($F = 6.21$, $p < 0.0001$). The models also indicated that survival was significantly higher in plots with vegetation removal *vs*. controls ($F = 5.85$, $p = 0.0173$).

Infiltration Rates

Infiltration rates varied considerably across the estuarine and elevation gradients (Appendix 2). (The lateral infiltration rates could not be estimated for the 0-5 cm part of the profile.) They were more variable than expected. Although it was expected that rates would be greatest in the upper elevation zones, it was less predictable than that. In some cases, the water table was encountered, and infiltration at particular depths did not occur in less than 24 hours (those were omitted). In general, lateral infiltration was faster than vertical infiltration rates, and upper elevation zones were typically higher, likely due to deeper sandy soils.

Conclusions and Implications for Future Research/Implementation

Estuarine communities at Eglin AFB display strong compositional trends that are significantly correlated with distance from the sea and elevation relative to East River. The effects of experimental storm surge across these two gradients vary in terms of abiotic conditions produced, the longevity of abiotic shifts, and plant mortality. The results of the first three interrelated experiments indicate that the effects of storm surge treatments on disassembly reassembly can be magnified or muted depending on soil and flooding conditions. Thus, effects of hurricane storm surge events are likely to not be uniform across these coastal transition ecosystems but rather modulated by the local environment.

Plant community assemblages appear to be more or less resilient (Standish et al. 2014) to storm surge, depending on its intensity and frequency. Although there were no statistical effects of the surges in the first experiment, doubling the volume in the second study produced treatment effects. The first surges may not have been sufficiently intense to override resilience of these coastal communities. Despite no discernible effects of the propagule additions, it is worth mentioning that those additions occurred after the first storm surge, which was the same volume as in the first experiment. It is possible that propagule additions following the second, more intense treatment would have led to colonization of seaward species. Many of those plots were virtually denuded and remained so in the growing season following the surge. The surge + sediment appears to have had driven a dramatic pattern of disassembly, followed by very slow recovery over multiple years. These surges were multi-faceted disturbances in that they included both saline intrusions and burial by sediment. The long “regeneration windows” created by such perturbations may provide crucial opportunities for migrating species as they increase the time in which interception of propagules can occur and lead to successful establishment.

This project sought to address whether anticipatory (futuristic) restoration is feasible. Based on rapid climate change and lack of spatial contiguity in an increasingly fragmented landscape, restoration with an eye to the future and the utility of assisted migration must be considered. Based on the results of the fourth experimental study, the general conclusion is “yes”. However, there are some caveats. The degree to which it is feasible and successful will differ depending on the species involved and the rate of background environmental and anthropogenic change. There are likely to be “ecological surprises”, including novel species interactions (e.g., terrestrial herbivores and *Spartina*) and disturbances in the new environs. The rate and direction of underlying abiotic change is a key driver that will dictate how far into the future restoration can be pushed.

Coastal communities provide an excellent model to study futuristic restoration because communities that are sequentially arranged along strong environmental gradients are likely to follow a “rolling carpet” model with climate change (Brinson et al. 2005). Use of common futuristic garden experiments at natural ecotones in the landscape could be used to screen and therefore guide feasible and useful restoration efforts.

Literature Cited

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Appendices

A. Supporting Data

Appendix 1. Soil texture profile by transect and elevation.

Gradient Position	% Sand	% Silt	% Clay
1 – Low	83.5 ± 4.3	6.5 ± 2.1	9.9 ± 2.3
1 - Middle	89.4 ± 1.5	5.6 ± 0.8	5.0 ± 0.8
1 – Upper	92.9 ± 0.6	2.7 ± 0.5	4.4 ± 3.6
2 - Low	61.2 ± 4.9	16.1 ± 1.6	22.7 ± 6.2
2 - Middle	93.5 ± 0.8	3.2 ± 0.6	3.3 ± 0.6
2 - Upper	94.5 ± 0.7	1.7 ± 0.2	3.8 ± 0.6
3 – Low	72.2 ± 10.0	18.3 ± 7.0	9.6 ± 3.7
3 – Middle	92.7 ± 0.6	3.1 ± 0.5	4.2 ± 0.4
3 - Upper	95.1 ± 0.7	2.2 ± 0.6	2.7 ± 0.2
4 – Low	79.9 ± 1.5	12.0 ± 1.5	8.1 ± 0.7
4 – Middle	91.9 ± 1.3	3.9 ± 0.8	4.1 ± 0.6
4 – Upper	93.7 ± 0.6	2.9 ± 0.5	3.9 ± 0.5
5 – Low	77.6 ± 4.1	15.6 ± 3.2	6.8 ± 0.9
5 – Middle	88.5 ± 2.9	6.9 ± 2.4	4.6 ± 0.7
5 – Upper	92.9 ± 0.7	3.3 ± 0.7	3.8 ± 0.3

Appendix 2. Averages and standard errors for vertical infiltration rates (first table) and lateral infiltration rates (second table), organized by transect (1 is the most seaward and 5 is the most inland), elevation zone (zones 2 was 2 m upslope of East River and zone 3 was 3 m upslope of East River), and soil depth (5, 25, and 50 cm).

	Average (seconds)	Standard error
Transect 1		
Zone 2		
5 cm	1362.0	139.0
25 cm	569.3	173.2
50 cm	430.0	156.0
Zone 3		
5 cm	1310.3	54.5
25 cm	678.0	299.0
50 cm	478.0	139.5
Transect 2		
Zone 2		
5 cm	101.3	27.7
25 cm	941.5	576.5
50 cm	.	
Zone 3		
5 cm	3309.3	1375.5
25 cm	2537.7	1190.0
50 cm	3885.0	621.3
Transect 3		
Zone 2		
5 cm	3710.7	1979.9
25 cm	66068.0	
50 cm	71965.0	
Zone 3		
5 cm	2435.3	336.8
25 cm	382.7	131.7
50 cm	7324.3	1041.2
Transect 4		
Zone 2		
5 cm	865.7	62.9
25 cm	935.7	375.0
50 cm	691.3	163.3
Zone 3		
5 cm	684.7	206.9
25 cm	640.7	91.1
50 cm	3317.0	615.2
Transect 5		
Zone 2		
5 cm	226.3	48.1
25 cm	733.3	74.7
50 cm	1551.7	352.2
Zone 3		
5 cm	462.7	130.4
25 cm	323.3	83.8
50 cm	612.3	498.6

	Average (seconds)	Standard Error
Transect 1		
Zone 2		
25 cm	421.0	224.4
50 cm	208.0	72.4
Zone 3		
25 cm	199.0	24.4
50 cm	158.3	38.8
Transect 2		
Zone 2		
25 cm	175.3	74.8
50 cm	.	
Zone 3		
25 cm	198.3	33.7
50 cm	144.0	22.5
Transect 3		
Zone 2		
25 cm	1770.0	247.6
50 cm	2205.3	490.0
Zone 3		
25 cm	55.3	2.7
50 cm	70.0	23.5
Transect 4		
Zone 2		
25 cm	134.7	68.3
50 cm	752.7	360.1
Zone 3		
25 cm	94.0	16.9
50 cm	148.0	30.7
Transect 5		
Zone 2	107.7	
25 cm	98.7	14.6
50 cm	116.7	8.6
Zone 3		
25 cm	102.0	13.7
50 cm	116.7	19.9

B. List of Scientific/Technical Publications

1. Articles in peer-reviewed journals

Abbott, M. J. and **L. L. Battaglia**. 2015. Purple pitcher plant (*Sarracenia rosea*) dieback and partial community disassembly following experimental storm surge in a coastal pitcher plant bog. *PLOS One*. 10(4): e0125475. DOI: 10.1371/journal.pone.0125475.

Tate, A.S. and **L. L. Battaglia**. 2013. Disassembly and reassembly of coastal communities following experimental storm surge and wrack deposition. *Journal of Vegetation Science* 24: 46-57.

2. Technical reports (not applicable)

3. Conference or symposium proceedings referenced (not applicable)

4. Conference/symposium and invited presentations

Battaglia, L. L. Assisted colonization of coastal communities: results of a futuristic transplant garden experiment. Oral presentation. CEER (Conference on Ecological and Ecosyste3m Restoration). Elevating the Science and Practice of Restoration: a Collaborative Effort of NCER and SER. July 28-Aug 1, 2014. New Orleans LA. International Meeting.

Battaglia, L. L. Assisted colonization of coastal communities: results of a futuristic transplant garden experiment. Oral presentation. Biennial meeting of the Coastal Estuarine Research Federation. November 3–7, 2013. San Diego, CA. International Meeting.

Battaglia, L. L., M. J. Abbott, A. D. Chupp, D. Harshbarger and J. Fruchter. Effects of hurricane storm surge and sediment deposition on coastal plant communities. Oral presentation. Annual meeting of the Society of Wetland Scientists. Duluth, MN. June 2 – 6, 2013. International meeting.

Battaglia, L. L., M. J. Abbott, A. D. Chupp, J. Fruchter and D. Harshbarger. Effects of hurricane storm surge and sediment deposition on coastal plant communities. Oral presentation. 98th annual meeting of the Ecological Society of America. August 4-9, 2013. Minneapolis, MN. National Meeting.

Battaglia, L. L. Assisted colonization: how far is too far? Results of a futuristic transplant garden experiment. Oral presentation. 97th Annual Meeting of the Ecological Society of America. August 5-10, 2012. Portland, OR. National Meeting.

Abbott, M.J. and **L. L.Battaglia**. Effects of experimental storm surge and sedimentation on pitcher plants (*Sarracenia purpurea*) in a coastal pine savanna. Oral presentation. 97th Annual Meeting of the Ecological Society of America. August 5-10, 2012. Portland, OR. National Meeting.

Battaglia, L. L and H. J. Kalk. Use of assisted migration and community zonation patterns to build a climate-resilient coastal landscape. Oral presentation, Annual meeting of the Society of Wetland Scientists (joint meeting with INTECOL). Orlando, FL. June 3 – 8, 2012. International meeting.

Battaglia, L. L., M. J. Abbott, A. D. Chupp and J. Fruchter. Effects of experimental storm surge and sediment deposition along an estuarine gradient in northwestern Florida, U.S.A. Oral presentation. Annual conference of the Society of Wetland Scientists. Prague, Czech Republic. July 3-8, 2011. International meeting.

Battaglia, L. L., M. J. Abbott, A. D. Chupp and J. Fruchter. Effects of experimental storm surge and sediment deposition along an estuarine gradient in northwestern Florida, U.S.A. Oral presentation. Annual meeting of the International Association for Vegetation Science. Lyon, France. June 20-24, 2011. International meeting.

Battaglia, L. L., M. J. Abbott, A. D. Chupp, J. Fruchter, J. Looft, and A. Thalhammer. Short term effects of experimental storm surge along a coastal transition ecosystem in northwestern Florida. Poster presentation. 15th annual Partners in Environmental Technology Technical Symposium & Workshop. Washington, D.C. November 30-December 2, 2010. National meeting.

Tate, A. S. and **L. L. Battaglia.** Are hurricane-generated storm surge and wrack deposition stepping stones for community reassembly? Oral presentation. Annual meeting of the Ecological Society of America. August 1-6, 2010. Pittsburgh, PA. National meeting.

Battaglia, L. L. Effects of storm surge disturbance on plant communities across a coastal transition ecosystem in northwestern Florida, USA. Oral presentation. Annual meeting of the Ecological Society of America. August 1-6, 2010. Pittsburgh, PA. National meeting.

Whitehurst, H., J. Martinez, C. Swift, J. A. Looft, A. S. Tate and **L. L. Battaglia**. Salt and wet: effects of artificial storm surges on Gulf Coast wetland species. Poster presentation. Annual meeting of the Ecological Society of America. August 1-6, 2010. Pittsburgh, PA. National meeting.

Battaglia, L. L. Effects of storm surge disturbance on plant communities across a coastal transition ecosystem in northwestern Florida, USA. Oral presentation. Annual meeting of the Society of Wetland Scientistis. June 27 – July 2, 2010. Salt Lake City, UT. International meeting.

Battaglia, L. L. Does hurricane disturbance facilitate landward migration of coastal species along a tidal river ecosystem? Results of a storm surge experiment. Invited seminar speaker. June 9, 2010. Pymatuning Seminar Series, University of Pittsburgh.

Battaglia, L. L. Does hurricane disturbance facilitate landward migration of coastal species along a tidal river ecosystem? Results of a storm surge experiment. Invited seminar speaker. April 30, 2010. Department of Environmental and Plant Biology Seminar Series, Ohio University.

Battaglia, L. L., M. S. Woodrey, H. J. Kalk and M. A. Foster. Back to the future: how do we develop ecologically appropriate targets for restoration under increased climatic extremes? Invited symposium presentation. 19th Conference of the Society for Ecological Restoration International. August 23-27, 2009. Perth, Australia. International meeting.

Tate, A. S. and **L. L. Battaglia**. A conceptual framework for examining the effects of hurricane-generated wrack deposition on coastal plant communities. Poster presentation. Annual meeting of the Society of Wetland Scientists. June 21-26, 2009, Madison, WI. International meeting.

5. Book chapters

Battaglia, L. L., M. S. Woodrey, M. S. Peterson, K. S. Dillon and J. M. Visser. 2012. Wetland Ecosystems of the Northern Gulf Coast. In: D. Batzer and A. Baldwin, editors. *Wetland Habitats of North America: Ecology and Conservation Concerns*. Pages 75-88. University of California Press.

C. Other Supporting Materials (not applicable)